DELHI UNIVERSITY
LIBRARY

DELHI UNIVERSITY LIBRARY

Cl. No. MD525 Jo

Ac. No. 122964 Date of release for loan

This book should be returned on or before the date last stamped below. An overdue charge of Six nP. will be charged for each day the book is kept overtime.

~~7 MAY 1960~~

~~6 MAY 1960~~

~~24 JAN 1961~~

~~7 [illegible] 1962~~

13 AUG 1964

~~2 NOV 1965~~

9 AUG 1967

ELEMENTS OF
PRACTICAL NAVIGATION

ELEMENTS OF PRACTICAL NAVIGATION

by

B. T. JONES

with a foreword by
Captain
Sir DAVID BONE
C.B.E., LL.D., (M.N. Retd.)

E. & F. N. SPON LTD
22 *Henrietta Street, London, W.C.*2
1950

Printed in Great Britain for E. & F. N. Spon Ltd.
22 Henrietta Street, Strand, London, W.C.2. by
The Garden City Press Ltd., Letchworth, Herts.

PREFACE

Since the beginning of the Second World War there have been many developments in the instruments and methods of Navigation. A detailed and up-to-date text book on the subject can no longer be adequately published in one volume, and the object of this book is, therefore, to summarize in compact form the essentially practical aspects, in the light of recent innovations.

PART I —PILOTAGE deals with the question primarily from the angle of the amateur mariner, equipped with only compass, charts and almanac.

PART II —ASTRONAVIGATION describes "rule-of-thumb" methods of calculating positions from observations of celestial bodies.

PART III—RADIONAVIGATION gives a brief description of wireless and radar navigational aids, the complexity of which defies simple explanation.

PART IV —AIR NAVIGATION covers the principal instruments, regulations and methods used in aircraft.

Acknowledgement is made to the Controller of H.M. Stationery Office for permission to publish extracts from the *Nautical* and *Air Almanacs*, to the Hydrographic Office of the U.S. Navy for figures from HO.208, and to S. M. Burton, Esq., for permission to use values from his *Nautical Tables*.

Autumn, 1949. B. T. JONES

"The Arte of Navigation demonstrateth how, by the shortest good way, by the aptest direction, and in the shortest time, a ship . . . be conducted."

John Dee, 1570

CONTENTS

Page

PREFACE 5

FOREWORD BY CAPTAIN SIR DAVID BONE 13

PART I—PILOTAGE

CH. I. THE COMPASS 17

The Magnetic Compass—The Binnacle—Compass Errors—Allowance for Variation and Deviation—Determination of Deviation—Swinging by Terrestrial Bearings—Swinging by Azimuth—Amplitudes—Alternative types of Compasses.

CH. II. CHARTS AND COURSES 29

The Form of the Earth—Projections—Chartwork—Sailing Instructions—Correction of Admiralty Charts—Courses—Rendezvous.

CH. III. POSITIONS, DISTANCES AND SPEED 38

Determination of a Position—Determination of Distances—Estimation of Speed.

CH. IV. NAVIGATIONAL AIDS AND REGULATIONS 46

Lights—Lightships and Wreck-Marking Vessels—Buoyage—Leading Marks—Rule of the Road—Sound Signals—Navigation Lights.

CH. V. TIDES AND SOUNDINGS 56

Definitions—Tidal Streams—Tides—Calculation of Times and Heights — Lunitidal Intervals — Soundings.

PART II—ASTRONAVIGATION

CH. VI. OBSERVATIONS 67

Astronavigation—Measurement of Time—Instruments—The Astronomical Position Line—Calculation of Observations—Plotting an Observation—Rules for Accurate Observations—Stellar Observations.

Page

CH. VII. CALCULATIONS WITH THE "R. & E." ALMANAC 78

Almanacs—Marc St. Hilaire Sunsight Calculation—Calculation of Moon, Star or Planet Sight.

CH. VIII. CALCULATIONS WITH THE "G.H.A." ALMANAC 84

The Greenwich Hour Angle—Calculation of Observations.

CH. IX. SPECIAL OBSERVATIONS 88

The Pole Star—The Meridian Altitude—The Ex-Meridian Altitude.

CH. X. ORIENTATION 91

The Sun—The Moon—The Stars.

PART III—RADIONAVIGATION

CH. XI. RADIO AIDS 97

M.F./D.F.—Errors—Procedure—Radiobeacons—Synchronized Radio & Sound Signals—Consol—Chart Abbreviations.

CH. XII. RADAR-ASSISTED NAVIGATION 103

Primary Radar — Secondary Radar — Pulsed Position-Fixing—Phase-Comparison Position-Fixing—Chart Abbreviations.

PART IV—AIR NAVIGATION

CH. XIII. FUNDAMENTAL PRINCIPLES 117

Dead Reckoning—Map Reading.

CH. XIV. NAVIGATIONAL INSTRUMENTS 120

Compasses—Altimeters—Air Speed Indicators—Drift Measurement—The Sextant—General Radio-navigational Aids—Approach and Landing Aids.

CH. XV. NAVIGATIONAL REGULATIONS 131

Right of Way—Air Traffic Rules—Movement Signals and Ground Marks—Aerodrome Lighting.

BIBLIOGRAPHY 139

INDEX 141

ILLUSTRATIONS

		Page
1	The Mariner's Compass Card	18
2	Instruments for Chartwork	34
3	Course Correction	36
4	Interception	37
5	Chart Positions	40
6	The Horizontal Angle	41
7	Arc of Visibility	48
8	Buoyage	51
9	The Marine Sextant	70
10	The Spherical Triangle	72
11	The Observed Position	74
12	Time from the Stars	93
13	Block Diagram of Primary Radar	103
14	Corner Reflector	106
15	The Chart Comparison Unit	106
16	Hyperbolic Lines of Constant Time- or Phase-Difference	108
17	The C.R.T. Indicator Unit	109

TABLES

Table I—The Universal System of Channel Buoyage 50

II—Navigation Lights 53

III—Aircraft Navigation Lights 135

IV—Declinations and Solar Bearings 138

ABBREVIATIONS USED IN THIS BOOK

A.M.U.	Air Mileage Unit.
A.P.I.	Air Position Indicator.
A.S.I.	Air Speed Indicator.
A.S.T.	Apparent Solar Time.
A.T.M.C.	Admiralty Transmitting Magnetic Compass.
B.A.B.S.	Beam Approach Beacon System.
Co.	Course.
C.R.T.	Cathode-Ray Tube.
C.Z.D.	Calculated Zenith Distance.
Dec.	Declination.
D.F.	Direction Finding.
D.Lat.	Difference of Latitude.
D.Long.	Difference of Longitude.
D.M.E.	Distance Measuring Equipment
D.R.	Dead Reckoning.
D.W.E.	Deck-Watch Error.
D.W.T.	Deck-Watch Time.
E.P.	Estimated Position.
F.P.A.	First Point of Aries.
G.C.A.	Ground Control Approach.
G.H.A.	Greenwich Hour Angle.
G.M.T.	Greenwich Mean Time.
G.S.	Ground Speed.
H.A.	Hour Angle.
H.A.T.S.	Hour Angle True Sun.
(Nat) HAV	(Natural) Haversine.
H.W.	High Water.
H.W.F. & C.	High Water Full and Change.
I.E.	Index Error.
I.F.	Intermediate Frequency.
I.L.S.	Instrument Landing System.
Lat.	Latitude.
L.H.A.	Local Hour Angle.
L.M.T.	Local Mean Time.

Long.	Longitude.
L.S.T.	Local Sidereal Time.
L.W.	Low Water.
L.W.F. & C.	Low Water Full and Change.
Mer.Alt.	Meridian Altitude.
M.F./D.F.	Medium Frequency Direction Finding.
M.H.W.N.	Mean High Water Neaps.
M.H.W.S.	Mean High Water Springs.
M.L.W.N.	Mean Low Water Neaps.
M.L.W.S.	Mean Low Water Springs.
O.A.	Observed Latitude.
p.l.	Position Line.
P.P.I.	Plan Position Indicator.
R.A.	Right Ascension.
R.A.S.	Rectified Air Speed.
r.p.m.	Revolutions per Minute.
S.A.	Sextant Altitude.
S.B.A.	Standard Beam Approach.
T.A.	True Altitude.
Tan.	Tangent.
T.A.S.	True Air Speed.
T.B.U.	Time Base Unit.
T.C.	Total Correction.
T.M.G.	Track Made Good.
T.Z.D.	True Zenith Distance.
Tr.	Track.
W./S.	Wind Speed.
W.T./D.F.	Wireless Telegraphy Direction Finding.

FOREWORD

BY CAPTAIN SIR DAVID BONE

This short introduction to navigation has been addressed largely to the amateur sailor, the yachtsman and tidal enthusiast, and the great body of eager young R.N.V.R.'s who came to sea with us and took duty in the ships when we were hard pressed (and how well they did it !).

A moderate competence in sailorwork, in seamanship, may be acquired in the early years of service, largely by observation of the handwork and ship craft of the able hands ; but, until the demands of clerical and oral examinations for Certificates of Competency loom up to cloud the fair prospect of such fun and games, not very much attention is paid to " book-work " by the young apprentices on shipboard.

That at least was my considered opinion during many years of peaceful seafaring in square-rigged ships and in steamships of many types. . . . But, in the war, a recent experience when in command of an L.S.I. (L.) changed that view. The naval draft in the ship was officered by juniors of the R.N.V.R., and it was the interest shown by these eager young lads, not only in their own flotillas, when afloat and exercising independent of far control, but also in the navigations of their parent ship which caused me to revise my opinion.

I think it unlikely that the terms of duty and the routines of the watches in a merchant ship can have been any part of their training in *H.M.S. King Alfred*, whence they came to us, but that all were well primed for pursuit of sea lore was quickly apparent. Attendance on the ship's bridge was not part of their duty, yet the area nearby was the favoured lounging spot with many of them when not engaged in some task connected with flotilla operations. It was not only the desire for a " breather " in such airy surroundings that had brought them up from lounge or smoke-room, but rather the urge to see for themselves how the other sailors in the ship were making out—or perhaps to ferret the source whence the Olympians (whose other names might be S.N.O.L. or S.N.O.T. or A.M.L.O.) spoke them by loud-hailer in times of stress—for the naval ops. room was there established. . . . But many of them probably had ambitions to improve upon the quantum of sea knowledge they had brought from the stone frigate at Hove and sought what experience or knowledge could be gained by observing the manœuvres of convoy and the ways of flag signalling in a group of ships. It was not always possible, though, to accommodate our naval shipmates on the bridge where there were limits of space. At sea in war-time it was no place for the casual instruction and upbringing of even the most adaptable of recruits. So, something had to be done, and, eventually, a somewhat " matey " class in some matters of seamanship and navigation was formed.

In this manner it was that I became well acquainted with the amateur sailor to whom this book, ELEMENTS OF PRACTICAL NAVIGATION, may make its special appeal. It was, to us, quite a novel experience to expound the principles of " The Rule of the Road at Sea " and the vagaries of the mariner's compass to architects' apprentices, budding quantity surveyors and young schoolmasters. All were enthusiastic and, being of riper years and perhaps more advanced in general knowledge than the average sea apprentice in his initiate, were quick to pick out a sufficiency of nautical tit-bits from our rambling admonitions to serve them passably at the beach-heads. . . . I can do nothing better now than to recommend Mr. Jones' ELEMENTS OF PRACTICAL NAVIGATION to such enthusiastic if casual seafarers, like these former good shipmates I remember. D. W. B.

Part I—PILOTAGE

CHAPTER I

THE COMPASS

1. THE MAGNETIC COMPASS

Any magnet horizontally suspended will always lie in a North-South line, with the result that its two ends can be described respectively as *North-Seeking* (or *Red*), and *South-Seeking* (or *Blue*). This principle is the basis of the compass, which simply consists of a card moved by magnets freely suspended in air or liquid. A common form of the instrument thus comprises a glass-topped brass bowl, containing a mixture of water and alcohol. In the centre of a cross-bar is a pivot, and on this rests the sapphire cap of a copper float. To the latter is attached the mica compass card (fig. 1), with two or more magnetized needles beneath it.

The card should be as large as possible, and at least four inches in diameter. Photographed on to it are four quadrants, each of eight points, as follows :—

N	E	S	W
N by E	E by S	S by W	W by N
NNE	ESE	SSW	WNW
NE by N	SE by E	SW by S	NW by W
NE	SE	SW	NW
NE by E	SE by S	SW by W	NW by N
ENE	SSE	WSW	NNW
E by N	S by E	W by S	N by W
(E)	(S)	(W)	(N)

These can be divided into :
- 4 *Cardinal Points*, e.g. N, S, E, W
- 4 *Half-Cardinals*, e.g. NW, SE
- 8 *Intermediate Points*, e.g. NNE, ESE
- 16 *'By' Points*, e.g. N by E

In addition to its eight points, each quadrant is also divided into ninety degrees, such that North and South are 0°, while East and West are 90°. The proper way of describing bearings is to name first NORTH or SOUTH, then the number of degrees, and lastly EAST or WEST; thus SOUTH-EAST would be given correctly as S45E. Recently the practice has been adopted of marking all compass cards from 0° to 360°. In this book, however, the old system of expressing Magnetic Bearings quadrantally has been retained.

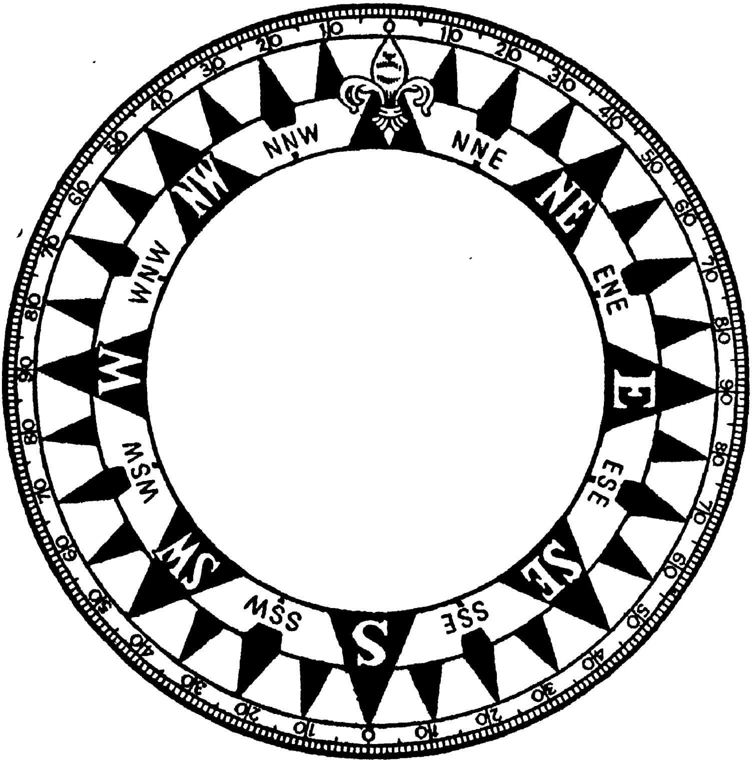


Fig. 1. THE MARINER'S COMPASS CARD

2. THE BINNACLE

The compass is slung in a stand called the *Binnacle* by means of *Gimbals*, or concentric rings with axes disposed 90° to each other, which allow the bowl to remain steady in spite of a ship's movement. Inside the bowl on the fore part is marked a thin *Lubber's Line*, representing the ship's head. The compass should be situated so that this line and the pivot are both parallel to the ship's centre-line.

Fitted for rotating round the top of the bowl should be an *Azimuth Circle*, comprising a ring and prism enabling an observer to see a reflection of the compass card, when looking at an object. This is essential for taking accurate bearings, but should the device not be available then bearings must be taken by surveying an object over the top of the card, keeping the eye in line with the card's centre. The farther degree, over which the object appears, is the required bearing.

3. COMPASS ERRORS

(*a*) **Variation.** If two magnets are placed close together, the Red end of one will attract the Blue end of the second—or, similarly, will repel its Red end. Now, the general magnetic effect of the Earth is similar to that caused by a powerful magnet placed at its centre, with the Blue end towards Hudson Bay, and the Red end towards South Victoria Land. Thus a compass needle, being virtually the Red end of a magnet, would, if not influenced by any local attractions, point to a *Magnetic North* instead of the *True* or Geographical one. The difference between these two is called *Variation*, a factor which alters both annually and with geographical position.

(*b*) **Dip.** In actual practice, a compass needle only lies completely horizontal at the Magnetic Equator. In Northern latitudes the Red end is inclined downwards, and in Southern latitudes upwards. The angle between the needle and the horizontal is known as the *Angle of Dip*, and varies with change of magnetic latitude (which is not quite the same as geographical latitude).

(*c*) **Deviation.** Another drawback with a magnetic compass is that it is deflected from the Magnetic Meridian by the presence of magnetic fields in the ship's hull and fittings, and more especially by the *permanent* and *induced* magnetism found respectively in the hard and soft iron of a ship. Such metallic deflection is known as *Deviation* and is dependent mainly on the direction of the ship's head and the geographical position. The first factor, however, is often the only one taken into consideration, as a fairly great change in latitude is necessary to affect the Deviation.

The algebraic sum of Variation and Deviation is called *Compass Error.*

4. ALLOWANCE FOR VARIATION AND DEVIATION

Variation and Deviation are termed *Westerly* when the NORTH point on the compass is attracted to the WEST of the geographical NORTH-SOUTH line ; and, conversely, *Easterly* when it is deflected to the EAST. These factors make it necessary to consider bearings in three kinds :

(*a*) **The True Bearing.** This is relative to the geographical North, and is generally given in terms of 0°-360°.

(*b*) **The Magnetic Bearing.** This is relative to the Magnetic North—i.e., a True Bearing with Variation applied.

(*c*) **The Compass Bearing.** The bearing of an object as indicated by the compass, i.e., the Magnetic Bearing with Deviation applied.

As Variation is shown on all charts, Magnetic Bearings can be directly plotted and read off. It is necessary, however, to be able to convert Compass and True Bearings to Magnetic—and vice versa—and for such calculations the following law applies :—

When Correcting from True-to-Magnetic-to-Compass, Apply Westerly Corrections in a Clockwise Direction, and Easterly Anti-Clockwise. When Correcting from Compass-to-Magnetic-to-True, apply Corrections in the Opposite Direction.

For example :

Compass Bearing = N89W
Deviation = 6E
Magnetic Bearing = N83W

(Compass to Magnetic, Deviation Easterly, thus correct clockwise)

It can be seen that the difference between the True Bearing and the Compass Bearing is the Compass Error. It is thus possible to convert True to Compass, or vice versa, employing the Total Compass Error.

For example : If Deviation=7°E and Variation=13°W,
Compass Error=6°W.
Then if True Bearing=N59E
and Compass Error = 6W (clockwise)
Compass Bearing =N65E

5. DETERMINATION OF DEVIATION

As already stated, Variation can be discovered from a chart, but the Deviation in a vessel is determined by a process known as *swinging* the ship. This should be carried out at least every few months, or at any time when an unusual compass error is suspected. Normally the operation can be effected unaided, but it is well worth occasionally employing a professional compass adjuster, who can often greatly reduce Deviation by well placed magnets.

Before swinging, it should be borne in mind that the compass and all adjacent metal objects must be in the positions they will occupy at sea, and if the compass has alternative positions, then the Deviation must be calculated separately for each. The principal methods of determining compass errors involve taking either Terrestrial Bearings or Astronomical Bearings—by Azimuth or Amplitude.

6. SWINGING BY TERRESTRIAL BEARINGS

Using this method, it is first necessary to select some conspicuous object, distant no less than five miles if possible. The vessel should then be firmly secured to a buoy, or by anchor, and swung in a complete circle around its moorings ; she should be steadied on each of the cardinal and half-cardinal points of the compass, and on each occasion the bearing of the object is noted.

In this way, the average of the eight results will be its correct Magnetic Bearing, and the difference between this and any one observed bearing will be the Deviation. An example is given below—

Ship's Head	Object Bearing	Deviation
N	N14W	10W
NE	N19W	5W
E	N26W	2E
SE	N30W	6E
S	N33W	9E
SW	N30W	6E
W	N24W	Nil
NW	N17W	7W
	8) 193	

Correct Bearing = N24W

If the object is near North or South, both Easterly and Westerly bearings may be obtained. If such is the case, take the sum of the Easterly bearings, and the sum of the Westerly bearings, subtract the smaller from the greater, and divide by eight. The result is the correct magnetic bearing East or West—whichever is greater.

Instead of using one conspicuous object, it is preferable if possible to secure the ship in such a position that bearings can be taken of two prominent objects in line (then said to be *in transit*, and indicated by the sign ϕ). The magnetic bearing on which the objects should thus appear can be determined from the chart, and saves errors in calculation.

On conclusion of swinging, a *Deviation Card* (p. 28) should be completed to show the Magnetic Course, Deviation and " Course to Steer "—to maintain the direction of the Magnetic Course. This " Course To Steer " is simply obtained by applying deviation to the magnetic course, according to the law of Sec. 4 above.

7. Swinging by Azimuth

Employing this principle, the vessel is again stopped on each of the cardinal and half-cardinal points, but now compass bearings are taken of the Sun, the correct bearing of which can be obtained with the aid of a *Nautical Almanac*, and a *Modified Weir's Azimuth Diagram* (Admiralty Chart No. 5000).

What is known as the *Local Mean Time* of the operation is first calculated, by adding or subtracting a *Longitude Difference* to the Greenwich Mean Time. This " Difference " is obtained from the ship's position (page 30) by multiplying the degrees and minutes of Longitude by four. In this way, minutes and seconds of time are obtained, and are *added* to the G.M.T. if the longitude is East, or *subtracted* if it is West.

The date and time of the operation are then looked up in the Nautical Almanac under the *Astronomical Ephemeris* tables headed Sun. From these are obtained values for " DEC " and " E." This factor " E " is then added to the L.M.T. and the result is called the *Hour-Angle.* The latter, together with the DEC and ship's latitude, is now applied to the azimuth diagram according to the instructions thereon. This will give the sun's true bearing, which can be converted to a magnetic bearing as already shown. A worked example of the system is given below :

	H M		
G.M.T. of operation	08 10	Ship's Position :	
Longitude Diff.	10	LAT 51° 27′N LONG 02° 35′ W	
	08 00		4
" E "	11 54	Longitude Diff.	10m 20s
Hour Angle	19 54	DEC = 19° 33′N	

The factors applied to the azimuth diagram are therefore :

HOUR ANGLE	19h. 54m
DEC	19° 33′N
LAT	51° 27′N

and these give a resultant sun's bearing of approximately 100° (S80E true).

8. AMPLITUDES

The third method of checking a compass error can be carried out while under way, and consists of taking an *Amplitude*, or bearing of the sunrise or sunset, and calculating the results with the azimuth diagram or nautical tables. As the latter are rarely found in small craft, and the method of Sec. 7 above is, under the circumstances, rather cumbersome, a table has been included on page 138 giving approximate sunrise and sunset bearings for latitudes in the United Kingdom. Constant for any year, these give *true* bearings of the sun when its upper limb is touching the horizon. For convenience, however, they are expressed quadrantally, instead of in the form 0-360°.

N.B.—The column headed DEC does not refer to these calculations, and should at this point be ignored.

Sunrise Bearings are Easterly and Sunset Bearings Westerly.

e.g. True bearing of sunrise in lat 55°N on March 12th =S85E.
True bearing of sunset in lat 55°N on March 12th =S85W.

Errors can thus be calculated by comparing compass bearings with this table, and applying the law of conversion. Following are two examples :

True Bearing of Sunrise	=S85E	True Bearing of Sunset	=S85W
Comp. Bearing of Sunrise	=S75E	Comp. Bearing of Sunset	=West
Comp. Error (Devn. + varn.)	=10E	Compass Error	=5W
If var'n=2W, then Devn.	=12E	If var'n=2W, then Devn.	=3W

9. Alternative Types of Compasses

Alternatives to the magnetic compass described above are :—

(*a*) **The Admiralty Transmitting Magnetic Compass** (ATMC). This is a special type which, in addition to its normal functions, can operate up to six repeaters in different parts of a ship. The unit works on 110 or 220 volts direct current, and consists simply of an ordinary liquid compass with platinum electrodes fitted to the card and bowl. The liquid is made slightly conductive, and a small current is passed between the electrodes such that, when the ship is on a set course, a balanced electrical " bridge " is formed, and no current flows. Any change of course, therefore, unbalances the bridge and sets up a voltage which is magnified sufficiently to energise a follow-up motor. In ATMC type I, the latter drives the compass bowl round in the opposite direction until the electrical balance is restored, and in this way it is possible for the course to be read from a large scale attached to the *outside* of the container. At the same time the follow-up motor drives a step-by-step transmitter which passes the compass heading to synchronous motors in the repeaters. ATMC type II is a larger and more powerful version, in which the Master compass is of a standard, 6-inch card, magnetic type, without the revolving bowl arrangement.

A.T.M.C. type III has been designed for use in aircraft, wherein is also found another variety of transmitting compass of the Gyromagnetic type. A.T.M.C. type IV is a special lightweight model with a North-seeking bowl locked electrically to the magnet system, thus avoiding liquid swirl. The necessary repeater circuits are obtained with the aid of the Total Error Corrector (T.E.C.) whereby two differential gears are inserted between the input repeater motor and output transmitter. Thus correction can be made for Variation and Deviation, and the type IV equipment can operate up to fifteen repeaters, showing True instead of Magnetic bearings.

(*b*) **The Gyroscopic Compass.** This consists of a 50 lb. wheel, 1 ft. in diameter and operated by electricity to spin in a vacuum at 8,600 r.p.m. It has a strong tendency to maintain its axis in a fixed direction, which can be made to coincide with *true* North. As with the ATMC, repeaters resembling ribbons or compass cards can be mounted in any part of the ship, and, when using these, one need not correct bearings or courses for variation and deviation. Its other advantages are that it immediately shows any alteration of course, and can be situated below the water line. On the other hand, it needs constant attention and has to be started up five hours before required for use. It is also entirely dependent on the electrical supply.

DEVIATION CARD
ERRORS OF STEERING COMPASS
OF *Yacht Daphne II*
DATE ....16/6/49................

DEVIATION	COURSE	COURSE TO STEER
10W	NORTH	N10E
	NNE	
5W	NE	N50E
	ENE	
2E	EAST	N88E
	ESE	
6E	SE	S51E
	SSE	
9E	SOUTH	S9E
	SSW	
6E	SW	S39W
	WSW	
NIL	WEST	WEST
	WNW	
7W	NW	N38W
	NNW	

CHAPTER II

CHARTS AND COURSES

1. THE FORM OF THE EARTH

The shortest distance between two points is the length of the straight line joining them. However, for navigational purposes the earth is regarded as a sphere,[*] and it is thus impossible to consider straight lines on its surface. Hence it is necessary to imagine the following regularly curved lines over the earth—

(*a*) **A Great Circle.** This is a circle on the surface of a sphere, whose radius and centre are those of the sphere itself (e.g., the Equator). The smaller arc (Orthodrone) of a Great Circle joining two places on a sphere measures their shortest distance apart.

(*b*) **A Small Circle.** This is a circle drawn on the surface of a sphere whose radius and centre are not those of the sphere (e.g., the parallels of latitude).

(*c*) **A Rhumb Line.** This is a regular curved line on the earth's surface, which cuts all meridians of longitude at the same angle. The meridians and the Equator are the only Great Circles which are also Rhumb Lines.

The earth rotates about an axis, the extremities of which are called the *North* and *South Poles*. Seen from above the North Pole, the direction of rotation is anti-clockwise. The general direction from which celestial bodies rise is called EAST, and the opposite direction is WEST.

---

[*] *In actual fact there is a* Compression, *or flattening, at the poles, and a slight outward extension in Longitude* 08° 15′*W.*

2. PROJECTIONS

Charts are nautical maps, which indicate dangers and aids to navigation, and on which a vessel's course and position are plotted. However, just as it is impossible to wrap a flat piece of paper smoothly round a sphere, so is it equally impossible to flatten out the surface of the sphere. In constructing maps and charts, the earth's surface is thus represented on paper by methods known as *Projections*.

One of the first of these was devised in 1556 by a Belgian, Gerard Kremer, who used the nom de plume *Mercator*. This system has been used ever since, and shows Rhumb Lines as straight lines. Sometimes, especially when long distances are involved, it is desirable to consider navigating along a Great Circle. For this purpose, charts are produced on *Gnomonic Projection*, whereby Great Circles are represented as straight lines.

Every Mercator's chart shows *parallels* of latitude running horizontally, and *meridians* of longitude drawn vertically at right angles. Graduation is in degrees North and South of the Equator or East and West of Greenwich respectively. Any definite position can thus be described by giving first its latitude, and then its longitude—e.g., 51° 27′N., 02° 35′W. Distances also are measured on the latitude scale, as one minute of latitude is equal to one *nautical mile*, approximately 2,000 yards. This value varies with latitude, and it is therefore essential when measuring distances on a

Mercator's chart to use that part of the vertical latitude scale abreast of the ship's track on the chart.

N.B.—One nautical mile per hour is called one *knot*, and it is, therefore, incorrect to talk of "knots per hour."

3. CHARTWORK

The first essential of efficient chartwork is thorough familiarity with the conventional abbreviations and signs. Space does not permit a list of these, but a diagram of them (Sheet No. 5011) can be obtained from any Admiralty chart-agent.

On each chart will be found two superimposed compass cards—or *roses*, the inner one of which indicates Magnetic Bearings, and the outer one True Bearings. The magnetic rose, which is at the moment divided into four quadrants of ninety degrees, will in future be graduated like the true rose—from 0° to 359° clockwise. This form of graduation will be brought into force as charts are taken up for correction. The difference between the two roses is, of course, the Variation on a particular date, and *when considering bearings, this must always be corrected with the aid of the indicated annual change.*

If, on a chart of a large area, lines are drawn linking all places where the Variation is the same, they are called *Isogonic Lines.* A *Variation Chart,* produced in this way, is a great asset when it is required to find the Variation at any place without unfolding the local chart.

4. SAILING INSTRUCTIONS

Official information essential to safe navigation is published as follows :

(*a*) "**Pilots.**" These are Admiralty Sailing Directions, published in a large number of volumes covering the whole world. New editions are issued every 10-12 years, and supplements produced at intervals of 15-18 months.

(*b*) **The Admiralty List of Lights.** This gives details of all navigational lights (except light buoys) and fog signals (other than W/T. fog signals).

(*c*) **The Admiralty List of Radio Signals.** Published in three volumes, this gives information about all coast wireless stations, WT/DF stations, broadcast weather bulletins, navigational warnings and time signals. It also gives the geographical positions, waves and characteristic signals of all radio beacons (p. 100) including those now installed in Ocean Weather Ships.

(*d*) **NEMEDRI.** A semi-permanent book of safe routeing instructions for the North European and Mediterranean areas, issued six-monthly in a single volume.

(*e*) **Navigational Warning Signals.** These include :

Naveams—covering the Eastern Atlantic and Mediterranean, broadcast from Portishead (Burnham).

Hydrolants—covering the Western Atlantic, broadcast from American East Coast stations and Halifax.

Hydropacs—for the Pacific Ocean East of longitude 103E but including the Gulf of Siam, broadcast from Honolulu.

These signals are reprinted in the weekly edition of:

(*f*) **Admiralty Notices To Mariners.** These are obtainable gratis from chart-agents, Custom offices and Mercantile Marine offices, etc. The weekly edition contains also corrections to NEMEDRI, the List of Lights and the List of Radio Signals.

5. CORRECTION OF ADMIRALTY CHARTS

Admiralty charts are supplied singly or in numbered, canvas-covered " folios " of geographical sequences. On supply they are corrected up to date, and should subsequently be amended from information promulgated in the Notices to Mariners. All corrections should be in ink except those from a *Preliminary* or *Temporary* notice, and these are inserted in pencil. Apart from cancelled " Temporary " corrections, *no erasures ought to be made from a chart* ; cancellations must be simply crossed through in ink. Some amendments are accompanied by " blocks," or reproduced portions of charts, and unless their information can be copied by hand, these should always be pasted on to the chart.

The dates of all corrections must be entered beneath the bottom margin of a chart, and the following are the conventional methods :—

(*a*) Normal small corrections are indicated by the year and relevant Notice number, e.g., 1948^{105}.

(*b*) "Preliminary" or "Temporary" Corrections are represented likewise, only as follows:

$$\frac{105\ (P)}{1948} \text{ or } \frac{105\ (T)}{1948}.$$

(*c*) Minor corrections, based on information not published in a Notice, and of no importance to safe navigation, are shown in one of two ways:

1948 8.20 or 1948 (*VIII.* 20)

both of which represent 20th August, 1948.

6. COURSES

To proceed to a destination which cannot be seen from the starting-point, it is necessary for a ship to steer a *compass course*. For this purpose a line is drawn on the chart between the two places, and a *parallel rule* (or roller rule —fig. 2), is placed along it. The rule is then moved over the nearest magnetic compass rose, and the

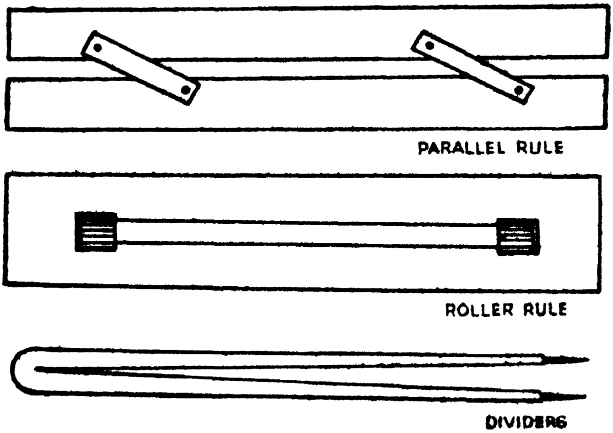


Fig. 2. INSTRUMENTS FOR CHART WORK

necessary magnetic course can be read off. This is converted to a compass course by applying Deviation in the usual manner. If possible the rule should be moved back from the rose to the course line—to ensure that no angular error or slipping has occurred.

Winds, currents and tidal streams (Chap. V) of known directions and speed, or rates, must be taken into consideration when estimating courses to steer, and the procedure adopted is best illustrated in the following examples :

(*a*) If a craft is proceeding at 5 knots on a compass course AB (fig. 3a) and there is a 3-knot tidal stream in the direction CD, then it will be necessary to discover the course which the vessel will really follow. If AX is stepped off for 5 miles along AB, and XY is drawn for 3 miles in the same direction as CD, then AY (produced if necessary) will be the required *course made good.* Likewise AY in terms of knots will be the *speed made good.*

(*b*) Alternatively, if a craft proceeding at 5 knots is wanting to steer from A to B (fig. 3b), and there is a 3-knot tidal stream in the direction CD, then it will be necessary to discover the *course to steer.* AX is again stepped off for 5 miles along AB, but now XY is drawn for 3 miles in the direction DC. AY is thus the course to steer to reach B, while AB is the course made good.

(*c*) Taking the problem of the above paragraph one stage further, if any point estimated by time and speed through the water is scaled off on the line AY, it can be transferred to the course made good by a line PQ (fig. 3c) parallel to XY. The point of intersection Q on the line AB will be the ship's *estimated position* (Chap. III).

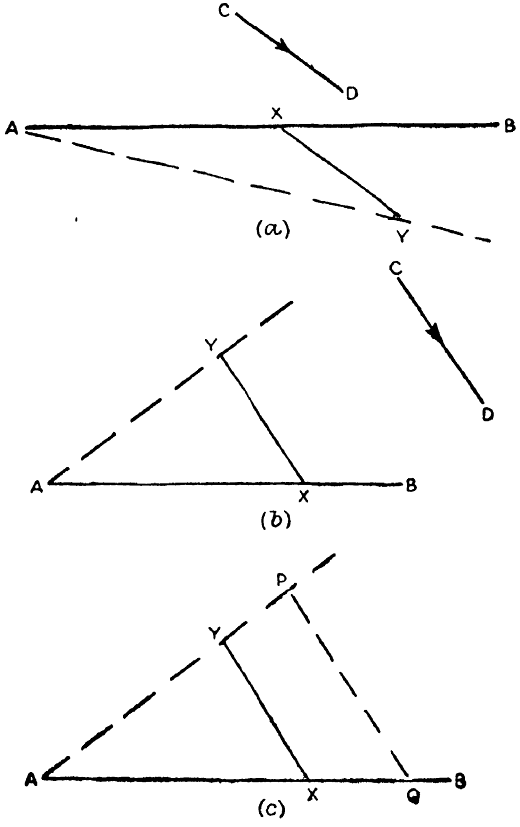


Fig. 3. Course Correction

7. Rendezvous

A vessel *A* wishing to rendezvous with another vessel *B* can determine the required course to steer by one of two methods :—

(*a*) If the course and speed of *B* are known, then the initial positions are plotted on the chart—A^1 B^1 (fig. 4) and a line drawn joining them. A second line *XY* parallel to A^1 B^1 is constructed through the position *B* will have reached one hour later (B^2). Finally a circle is drawn with centre A^1 and radius *A's* speed. Now, if a line is constructed from A^1 to the point A^2 where the circle cuts *XY*, this will be the required course to intercept *B*.

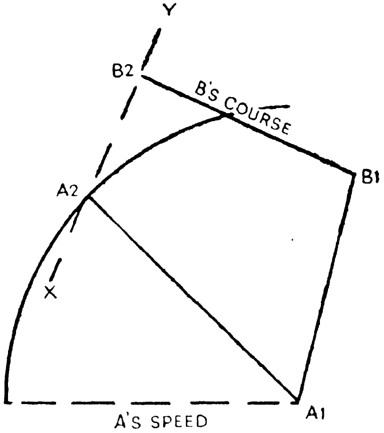


Fig. 4. INTERCEPTION

(*b*) If *B* is proceeding from a known position at a known speed, but on an unknown, constant course, then *A* can intercept—providing it has superior speed, and by applying what is known as the *Vignot Principle.* This consists of steering a course which is an equiangular spiral, such that the secant of the angle between radius and spiral is always equal to $\dfrac{\textit{Speed of A}}{\textit{Speed of B}}$

CHAPTER III

POSITIONS, DISTANCES AND SPEED

1. DETERMINATION OF A POSITION

The position of a vessel on a chart can be determined by any of the following methods :

(*a*) **Dead Reckoning** (DR). A " DR " position is found by simply plotting the course steered, for a distance dependent on the time and estimated speed (Sec. 3 below). Indicated on the chart by a cross, such a position does not allow for the effects of wind and sea, etc., and should only be taken as a quick and very rough method.

Vessels carrying a volume of nautical tables are able to calculate a DR without laying off the course. This is achieved with the *Traverse Table*, and is particularly useful when the course covers more than one chart.

If a ship proceeds in a straight line between two places *A* and *B*, the Easterly or Westerly movement in miles is known as *Departure*. This must not be confused with the *Difference of Longitude* (D. Long), which is the same distance measured in degrees and minutes of longitude. Should the vessel's course lie continuously on one parallel of latitude then the departure is just the distance covered ; if, however, *A* and *B* are on different parallels the departure is now the length of the arc of a *Middle Latitude* lying between the two. For practical purposes, involving distances of less than six hundred miles, this is assumed to be the *Mean Latitude* half-way between *A* and *B*. The relation between D. Long. and departure is—

DEPARTURE = D. LONG. *x cosine* MIDDLE LATITUDE.

If a course and distance travelled are applied to a Traverse Table, it is possible to determine the departure and *Difference of Latitude* (D. Lat.) between the starting-point and destination. From the initial latitude and D. Lat., the Mean Latitude can be computed, and if this is entered in the table the departure value can be converted into D. Long.

The differences of longitude and latitude, therefore, enable the final DR position to be determined from the original. Conversely, it is possible to utilise this principle for calculating a course between two known points.

(*b*) **Estimation.** An *Estimated Position* is found by applying the estimated effect of wind, current and tidal stream to the DR. Indicated thus ΔEP., it should also not be taken as really accurate or reliable.

(*c*) **Fix.** To obtain a vessel's accurate position on a chart, it is necessary to lay off *Position Lines* representing bearings of landmarks, etc. This necessitates first obtaining a compass bearing of any such point, and converting it into a magnetic or true bearing by the method on p. 21. A parallel rule is then placed on the chart over the nearest magnetic rose to the landmark in such a way that its edge runs from the centre of the rose to the obtained bearing (as a check for accuracy, it is a good plan to place it over the reciprocal bearing as well). Retaining this angle, the rule is then moved over the chart until its edge cuts the landmark. If a line is now drawn along that edge, then somewhere on its path lies the ship's position.

If bearings are taken simultaneously of two or more landmarks, the point on the chart where their respective position lines intersect is the ship's position. This is known as a *Fix*. Often, however, three or more such lines do not meet exactly in one point, but form a small triangle known as a *Cocked Hat*. It is customary to mark the ends of the position lines with single arrowheads, as shown in the 1150 position of fig. 5.

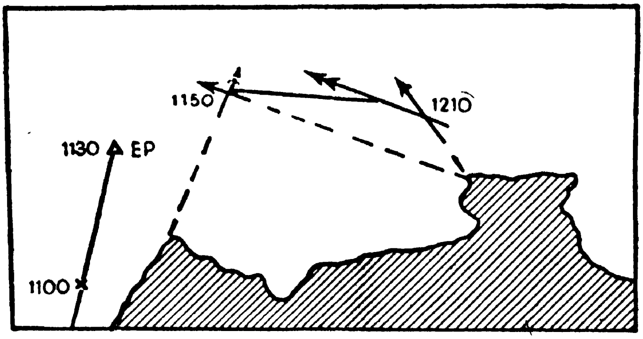


Fig. 5. CHART POSITIONS

(*d*) **Running Fix.** A *Running Fix* is obtained by taking two position lines on a single landmark at different times. From any point on the first the estimated course and speed are laid off, and through the resulting position a line is drawn parallel to the first position line. The ship's position will be where this cuts the second, p. l. A Running Fix is identified from a Fix by putting a second arrowhead on one of the lines, as in the 1210 position.

(*e*) **Fix By Horizontal Angle.** Another application of the Fix principle involves the use of a sextant and a sheet of tracing paper. First it is necessary to select three landmarks, *A*, *B* and *C* (fig. 6), and measure the horizontal angle between *A* and *B* also *C* and *B*. A line *XB* is now drawn on the paper representing the path between the ship and object *B*. In this way *XA* and *XC* can be constructed on either side of *XB* at angles equal to those already obtained. The paper is then placed on the chart, and moved about until the three lines lie exactly on the charted positions of the landmarks *A*, *B* and *C*; and thus it follows that *X* is the ship's position at the time of measuring the angles.

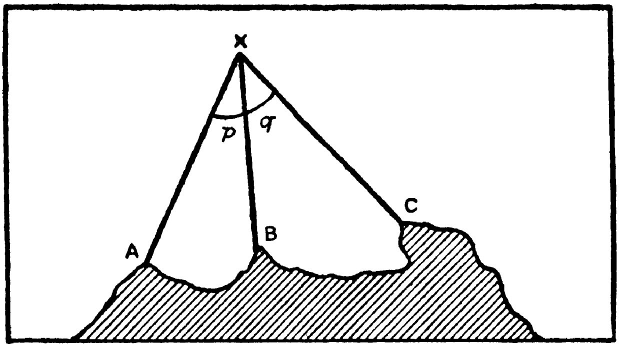


Fig. 6. THE HORIZONTAL ANGLE

(*f*) **Doubling the Angle on the Bow.** If the time is noted when the angle between the ship's head and the line of bearing of a landmark is x°, and again when it is 2x°, then it follows that the distance run by the ship between the observations is equal to its distance from the landmark at the second observation. If the bearings are taken when the angles are 45° and 90° from the ship's course (i.e., on the bow and beam) then the result obtained is called a *Four-Point Bearing.* If the course and speed made good are not those estimated, it is obvious that the final distance will be in error.

(*g*) **Soundings.** For checking positions it is essential to stress here the value of soundings, and lines of soundings, the measurement of which is explained in Chap. V.

2. DETERMINATION OF DISTANCES

It is clear that a vessel's position can also be determined if the bearing and distance off a single landmark are accurately known. Common methods of ascertaining distances from a ship are :

(*a*) **Portable Rangefinders and Distance Meters.** These are optical instruments whereby it is possible to determine the distance from an object of known height, or conversely the height of an object of known distance away. The method of operation consists of adjusting the instrument until an image of the top of the object appears level with the base of the true object. If the known height has been previously applied, the range is now shown, and if the range was applied then the height is indicated. When used for navigational purposes, such devices should be continually checked for errors. The two types of instrument in common use are the *Stuart's Distance Meter* which is accurate up to one mile, and the *Weymouth-Cooke Rangefinder,* which is used for ranges between one and nine miles.

(*b*) **The Vertical Angle.** This involves measuring with a sextant the angle between the top and bottom of a landmark of known height. Thence its distance from the observer can be calculated with tables such as Commander S. T. S. Lecky's *Off-Distance Tables*, or by means of the following equation :—

$$\frac{\textit{Height of Object in ft.} \times 0.565}{\textit{Angle in minutes}} = \textit{Distance in miles and tenths}$$

(*c*) **The Horizon Distance.** Under normal conditions of visibility the distance in nautical miles to the sea horizon can be taken as :—

$$1.15 \times \sqrt{\text{Height of Observer's eye in feet}}$$

From this it is possible to estimate the distance at which an object of known height will appear or disappear from view. For example :

If Observer's
Height of eye=220 ft., Horizon Dist. $=1.15\sqrt{9} = 3.4$m
And if height
of landmark=9 ft., ,, ,, $=1.15\sqrt{220}=17$ m
Thus maximum visibility of landmark=20.4m

(*d*) **Sound Echo Distances.** If an echo from a whistle or siren is heard from a cliffy coastline or large vessel at anchor, the distance can be determined very approximately by the following rough rule based upon a standard speed of sound (which is not, of course, constant though it only varies through small limits).

Distance in feet =*Echo Period in seconds* × 565
Distance in miles=*Echo Period in seconds* ÷ 11

N.B.—The behaviour of sound in fog is most capricious and it must not be assumed that if no echo is heard no cliff or reflecting object exists.

3. ESTIMATION OF SPEED

The *speed* of a vessel is always understood to mean its rate of advance *through the water*, as determined in the ways given below. It must NOT, however, be confused with the rate *over the ground* (i.e., over the chart), which for E.P.'s, etc., can be obtained by applying to the course and speed an allowance for currents and tidal streams. Methods of estimation are as follows :

(*a*) **Patent or Pressure Logs.** These measure distances travelled through the water, but in coastal sailing they are more of a luxury than a necessity. Alternatives therefore include :

(*b*) **The Dutchman's Log.** This is the name given to the principle of dropping overboard a small floating object from the forepart, and timing it over a measured distance to the stern, then—

$$\textit{Speed in knots} = \frac{\textit{Distance in feet}}{\textit{Time in seconds}} \times 0.6$$

(*c*) **The Log-Ship.** This comprises a small wooden triangle with a lead-weighted base. Attached to the corners is a long three-legged bridle, with one leg plugged in hand-tight to the socket at the inner end of the bridle. This enables the log-ship to be tripped flat at the end of the run and hauled in without strong resistance to the ship's speed. To the bridle is joined the log-line, and this is marked by paying out sufficient length to take the triangle clear of the ship's wake, and then tucking a piece of bunting into its strands. Thence the line is marked at every 25 feet, up to the maximum speed of the vessel. (e.g. Nine knots will require nine lengths of 25 feet.) Finally the line is wound on to a freely revolving reel.

When the " log " is streamed, the time is taken as the first piece of bunting passes over the stern, and the line is stopped when fifteen seconds have elapsed. The number of marks which have run out in that period, indicates the speed of the craft in knots.

(*d*) **The Engine Speed.** The distance which a ship's screw would travel in one revolution, if working in a solid, is known as its *pitch*—which is, incidentally, equal to the screw circumference in feet at the point where the blade angle is 45°. From this it follows that the speed of a screw in knots is equal to :

$$\frac{R.P.M. \times Pitch \times 60}{6080} \quad \text{or roughly} \quad \frac{R.P.M. \times Pitch}{100}$$

In water, however, there is a loss of distance, known as *slip*, such that if the speeds of the ship and screw are respectively A and B knots, then the *slip percentage* is equal to : $\frac{100\ (B-A)}{B}$.

With the aid of these equations, it is, therefore, possible to compute a table of corresponding revolutions and speeds for a ship with a screw of known pitch and slip.

CHAPTER IV

NAVIGATIONAL AIDS AND REGULATIONS

Complete uniformity in lights, buoyage, shiphandling and signals is most essential—both as an aid to mariners, and also to prevent collisions and wrecks. It is thus the duty of anyone in charge of even the smallest vessel under way to be thoroughly conversant with these conventions.

1. LIGHTS

Lights are exhibited from lighthouses, lightships and buoys, and each is distinguished by its individual combination of light, darkness and colour. All lights are, therefore, divided and described as follows :

(*a*) **Fixed (F)**	A continuous, steady light.
(*b*) **Flashing (Fl.)**	Showing flashes of light at regular intervals, the duration of light being less than that of darkness.
**Quick Flashing* (*Qk. Fl.*)	Flashing continuously more than 60 times per minute.
**Interrupted Quick Flashing* (*Int. Qk. Fl*).	Flashing more than 60 times per minute, with a total eclipse at regular intervals.

---

* *Recently introduced, and as yet rarely encountered.*

(*c*) **Occulting (Occ.)** A steady light eclipsed at regular intervals, the duration of light being greater than that of darkness.

(*d*) **Alternating (Alt.)** A light which changes colour.

Sometimes lights show flashes or eclipses at regular intervals in groups, and hence are known respectively as *Group Flashing* (*Gp. Fl.*), **Group Interrupted Quick Flashing* (*Gp. Int. Qk. Fl.*) and *Group Occulting* (*Gp. Occ.*). Likewise a fixed light is sometimes varied by a single flash or group of flashes of relatively greater brilliancy, and thus becomes *Fixed and Flashing* (*F. Fl.*) or *Fixed and Group Flashing* (*F. Gp. Fl.*).

The time occupied by one complete flash or cycle is known as its *period*, and lights are always described on charts by means of their type, period, height and visible range. For example :

Lt. Gp. Fl. (5) 30 *secs.*, 210 *ft.*, *vis.* 20 *m.*

This means a white light showing a group of five flashes every 30 seconds, the height of the lantern being 210 feet, and the visible range 20 miles to an observer whose height of eye is 15 feet (p. 53). The sign (*U*) would indicate that a light is unwatched, and thereby not entirely reliable. Air navigation lights are indicated as —*Air Gp. Fl.*—with a letter in brackets if they show it in Morse Code characteristics.

N.B.—(1) Bearings are always considered as from the ship's compass ; thus if a lighthouse is said to be visible *from South through East to West*, its arc will extend as in fig. 7.

---

* *Recently introduced, and as yet rarely encountered.*

(2) *The identity of lights should be verified by their characteristics, colour and period of flashing or occultation. Their identity should never be simply assumed.*

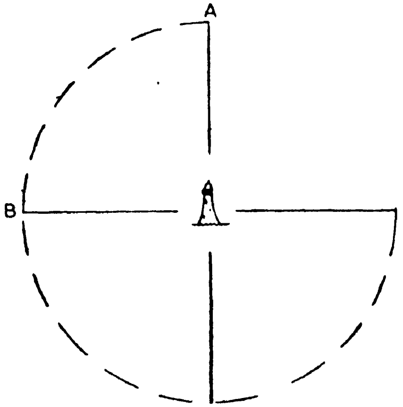


Fig. 7. ARC OF VISIBILITY

2. LIGHTSHIPS AND WRECK-MARKING VESSELS

(*a*) Except on the Irish coast, where they are black, lightships in Great Britain are painted red with their names in white. By day they carry a shape—or *daymark*—which is hauled down if the ship is off her station. In such an eventuality at night, the vessel exhibits a red light forward and aft, and a white flare every quarter of an hour.

(*b*) Vessels marking wrecks exhibit green balls by day, and green lights by night. These are hoisted vertically according to the following arrangement :

2 balls—ship to be passed on mariner's port hand ;
3 balls—ship to be passed on mariner's starboard hand ;
4 (2 and 2)—ship to be passed on either side.

3. Buoyage

Buoys are used to mark channels and shoals, and are fitted generally with a flashing or occulting light, often a fog sound signal, and sometimes a *topmark*, consisting of a shape on a staff. Nowadays many buoys are also fitted with radar devices (one type of which is shown in fig. 14). These are, nevertheless, of use to every navigator as an aid to identification in poor visibility. They are indicated on charts with the abbreviation *Ra. Refl.*, and radar beacons are shown with the word *Racon*, while other conspicuous radar installations are marked *Ra* (*conspic*). Buoys marking wrecks are painted green, and those indicating sewers are black and yellow. All channel buoys are marked from sea entering inwards, or with the main stream of flood tide. They are also often numbered in from seaward—odd on the *starboard hand*, and even on the *port hand*. The latter terms indicate the right- and left-hand sides of the channel respectively.

For the purposes of buoyage, the main stream of flood tide around the United Kingdom is as follows :

(a) English Channel, North & East coasts of Gt. Britain (excluding Moray Firth, Firth of Forth & Wash), Pentland Firth and between Orkney and Shetland Islands	Towards the estuary o the Thames
(b) St. George's Channel, Irish Sea (excluding Bristol Channel), North coast of Ireland (Tory Island to Rathlin Island), South coast of Ireland (Skelligs Rocks to Carnsore Point)	Towards Solway Firth on the East, and towards Lough Stragford on West
(c) West coast of Ireland from Skelligs Rocks to Tory Island	To the North
(d) West coast of Scotland, North of Mull of Cantyre, including the Hebrides	Towards Cape Wrath
(e) East and West coasts of Orkneys & Shetlands	To the South

The universal system of channel buoyage is shown in

Table 1 below, in which the following conventional abbreviations are used :—

B—Black R—Red Cheq.—Chequered
V.S.—Vertical Stripes H.B.—Horizontal Bars

Table 1 — BUOYAGE

Mark	Shape	Colour	Light (if any)	Topmark (if any)
Starboard Hand	Conical	B or B & W Cheq.	W flashing 1, 3 or 5 flashes	B Cone (point up) or B Diamond– except at channel entrance
Port-Hand	Can	R or R & W Cheq.	R-any number of flashes up to 4 or W-2, 4 or 6 fl.	Red can or *T*– except at entrance to channel
Middle-Ground	Spherical	*Main Channel to Right :—* R & W.H.B.	W or R distinctive character	Outer end–R can Inner end –R *T*
		Main Channel to Left :— B & W.H.B.	As above	Outer end–B cone Inner end–B diamond
		Channels of Equal Importance :— R & W.H.B.	As above	Outer end–R sphere Inner end–R St. George's Cross
Mid-Channel	Distinctive from above shapes	B & W.V.S. or R&W.V.S.	Distinctive from above lights	Distinctive from above topmarks
Isolated Danger Marks	Spherical	B & R.H.B. separated by narrow W band	W or R flashing	B or R sphere or Sphere horizontally divided–half B and half R
Landfall Marks	Subject to above rules	B & W.V.S. or R&W.V.S.	Flashing	—

N.B.—(1) *Bearings for fixing a ship's position must never be taken on buoys, or on the "loom" of a light.*

(2) *It is a punishable offence to ride by, or make fast to any navigational buoy.*

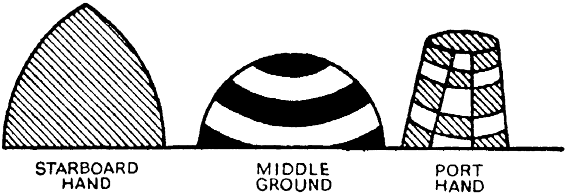


Fig. 8. BUOYAGE

4. LEADING MARKS

Leading Marks are often found in harbour approaches, and consist of two land marks, which, if kept in line (or *transit*), will lead a vessel through the best channel, or in the deepest passage over a swashway or bar. Such marks should be so spaced apart so as to give one-third of the greatest distance of the ship from the nearest mark in the required channel reach. The ratio should never exceed 7 to 1 as the transits then become insensitive and are unsafe.

5. RULE OF THE ROAD

As the *Highway Code* is to the motorist, so to the seaman are the *International Regulations for Preventing Collisions at Sea.* Unlike its counterpart, however, the guiding principle of the marine rule is to keep to the right. Thus, if two mechanically-propelled vessels are approaching each other head-on, each must alter course to starboard. If, on the other hand, they are crossing, it becomes the duty of the one which sees the other on her starboard side to keep out of the way. In this case, the second ship should maintain her original course and speed. Any vessel overtaking another shall keep out of the way of the overtaken ship. " Overtaking " implies approaching from more than 22½° abaft the beam.

A mechanically-propelled ship should always give way to sail, but, if two sailing craft are approaching each other, the following rules must apply :

(*a*) A vessel which is *running free* (i.e., with the wind abaft the beam, and the sheets eased away) shall keep out of the way of a vessel which is *close-hauled* (sailing as close to the wind as possible).

(*b*) When both are running free, with the wind on different sides, the vessel which has the wind to port shall keep out of the way of the other.

(*c*) A vessel which is close-hauled on the port tack shall keep out of the way of one which is close-hauled on the starboard tack.

(*d*) When both are running free, with the wind on the same side, the vessel to windward shall keep out of the way of the one to leeward.

(*e*) A vessel which has the wind aft shall keep out of the way of the other.

N.B.—Every craft should take compass bearings of another vessel, when approaching it ; if these bearings remain unchanged, then the ships are on a collision course, and prompt action will be necessary.

6. SOUND SIGNALS

A ship's intentions can be indicated with the following simple sound signals :

ONE SHORT BLAST —	"I am directing my course to starboard."
TWO SHORT BLASTS—	"I am directing my course to port."
THREE SHORT BLASTS—	"My engines are going full speed astern."
FOUR SHORT BLASTS—	"Keep out of my way, as I cannot keep out of yours." (Port Regulations.)

7. NAVIGATION LIGHTS

Table II shows the main navigation lights prescribed in the above regulations. Under these provisions, the word *Steam-vessel* includes any craft propelled by machinery, and the term *Under-Way* refers to any ship which is not at anchor, secured to the shore or aground. The indicated *Range* gives the visibility to an observer whose height of eye is 15 feet on a clear dark night.

TABLE II — NAVIGATION LIGHTS

CLASS OF VESSEL	COLOUR	POSITION AND REMARKS	RANGE	AREA OF VISIBILITY
Sailing Vessel of 20 tons, or over, under way	a. White	Overtaking light at the stern	2m	Right Astern to 22½° abaft the beam
	b. Red & Green	Port and st'bd sidelights	2m	Right Ahead to 22½° abaft the beam
Steam Vessel of 40 tons, or over, under way	a. b.	As above.		
	c. White	On foremast, at least 20 ft. above the hull	5m	Ditto.
Steam Vessel of less than 40 tons, under way	d. White	In forepart, 9ft. above gunwale	2m	Ditto.
	Red-Green	Combined lantern, at least 3ft. below (d)	1m	Ditto.

TABLE II — *Continued*

CLASS OF VESSEL	COLOUR	POSITION AND REMARKS	RANGE	AREA OF VISIBILITY
Vessel at anchor	e. White	20ft. above hull	2m	All round
Vessel not under command	2 Red	In vertical line, 6ft. apart. Also Anchor light (e) if aground	2m	All round. In daytime 2 black balls shown in lieu
Sailing Pilot Vessel	White	At masthead	3m	All round
	b. Red & Green	Sidelights shown on being approached	2m	As (b) above
	White-Flare	At short intervals not exceeding 10 min.		
N.B. A Steam Pilot Vessel shows these lights, but also :—	Red	8ft. below White Masthead Light	3m	All round
Vessel fishing	White	At masthead	2m	All round
	If its tackle extends for more than 150 ft. a similar light shall be shown 3ft. below the first, and 5ft. horizontally away in the direction of the tackle.			
Cable Ship	Red White Red	In vertical line at least 6ft. apart lowest 14ft. or more above hull	2m	All round By day 2 red rounds and 1 white diamond are shown in lieu
Steam Vessel towing	b. & c.	As above	2 & 5 m	Right ahead to 22½° abaft the beam
	White	6ft. above or below (c), but at least 14ft. above the hull	5m	Ditto.

N.B.—If more than one vessel is being towed and if length of the tow exceeds 600 ft., then a third similar white light must be shown 6ft. above (c), and at least 14 ft. above the hull.

It must be remembered that special craft, such as fishing, cable and pilot vessels, show only the lights of their tonnage when not employed on their specified tasks. No doubt it will also be noted that the table does not include sailing vessels of less than 20 tons—for these merely require a lantern with green glass on one side, and red on the other—so that the green shows only on the starboard side, and the red only on the port.

CHAPTER V

TIDES AND SOUNDINGS

1. DEFINITIONS

Confusion often arises through incorrect use of the words *current*, *tidal stream*, and *tide* :

(*a*) **A Current** is the horizontal movement of the surface water of the sea, which continues in the same general direction for some time, and is unrelated to tidal movement.

(*b*) **A Tidal Stream** is the horizontal movement of the surface water, which changes its direction according to the state of the tide.

(*c*) **A Tide** is the periodical vertical movement of the sea.

2. TIDAL STREAMS

(*a*) **Slack Water.** Changes in the direction of tidal streams do not always coincide with the change of vertical tidal movement, and are often two to three hours later. The interval between the cessation of a stream and its commencing to run in another direction is termed *slack water.*

(*b*) **Set and Drift.** The direction and velocity of tidal streams and currents are known respectively as *set* and *drift.*

(*c*) **Direction and Rate.** The direction and rate of any tidal stream can be found in Part III of the *Admiralty Tide Tables*, in the appropriate *Sailing*

Directions, and—for the United Kingdom—from *Tidal Stream Charts* drawn in relation to times of high water at Dover. Admiralty charts often contain tables or notes giving the times of Slack Water and the rate of tidal streams. Where the tabular form is not used, certain charts show tidal stream arrows. At any moment, however, the rate of flow of a tidal stream can be roughly calculated from the maximum average rate shown on the chart, by means of the following table :

1st Hour	1/3 of maximum	4th Hour	1/1 of maximum
2nd Hour	2/3 of maximum	5th Hour	2/3 of maximum
3rd Hour	1/1 of maximum	6th Hour	1/3 of maximum

These rules, however, do not apply where double-day tides prevail (para. 3 (*d*) below). Tidal streams should always be used to advantage, but it must be remembered that a tide at any state will invariably set into a bay and towards the land. It is, therefore, essential always to allow for such *insets*, which are frequently experienced around the coasts of the United Kingdom.

3. Tides

(*a*) **Ebb and Flood.** Tides are said to rise or *flood* to a maximum level, known as *High Water*, and fall or *ebb* to a minimum level, known as *Low Water*. Such a rise and fall occurs normally twice every 24 hours (except in the case of double-day tides—3 (*d*) below). High Water times occur about 30 to 70 minutes later each day. The period at high water between the tide's ceasing to rise and starting to fall is known as its *stand*.

(*b*) **Range and Duration.** The time between high water and the preceding or following low water is called the *duration* of a tide—while the difference in the height of the water between these two times is known as its *range*. The latter is by no means an invariable factor, for every fortnight, with the full and new moon, tides known as *springs* will be found unusually high and correspondingly low. Alternating tides of least range are called *neaps* ; but, in their turn, both springs and neaps are in no way constant. The range of the springs will be found greatest, and that of the neaps least, at about the time of the equinoxes—i.e., towards the end of March and September. In view of these variations, depths of high and low water have to be classified according to averages, in the following manner :

Mean High Water Springs (MHWS)-average h.w. height of the springs
Mean High Water Neaps (MHWN)- „ „ „ , „ neaps
Mean Low Water Neaps (MLWN)- „ l.w. „ „ „ neaps
Mean Low Water Springs (MLWS) - „ „ „ „ „ springs

The difference in height between MHWS and MHWN is the same as that between MLWS and MLWN.

(*c*) **Heights, Soundings and Datum.** On Admiralty charts all terrestrial heights are given in feet above MHWS while underlined figures on shaded drying banks show the number of feet the bank will dry out at MLWS. A figure beneath a line—e.g., $\overline{100}$ signifies that no bottom has been found at the depth indicated. On all such charts, the units of soundings are prominently defined under the main title — e.g., " Soundings in Feet," and this is the first feature to note before looking at the soundings themselves. The level below which depths are given is known as the *chart datum*—which is regarded as the level below which

Low Waters seldom fall. It is approximately equal to MLWS, but is quoted on each Admiralty chart—either in general terms or to the nearest foot on large-scale plans. The difference between Datum and High Water on any given day is called the *rise* of the tide.

(*d*) **Double-Day Tides.** Owing to shallow water effects in the English Channel between the Selsey and Portland Bills, there occurs a *double-day tide*, which is most pronounced in the Solent and Southampton Water. At Portsmouth, Havre and Honfleur, this phenomenon takes the effect of a prolonged stand at High Water ; whilst at Southampton the spring tides have two separate high waters of about equal height, with an interval between them of nearly two hours. At neap tides, this resolves into one prolonged stand at High Water. At Weymouth the effect is that of a double low water, known as the *Gulder.*

(*e*) **Meteorological Tides.** These are periodic changes in the sea level due to seasonal winds and changes of atmospheric pressure, etc. It must also be remembered that an abnormally high barometer is always accompanied by a depression in mean sea level which may reduce depths to values several feet less than those shown for MLWS on charts. Local winds blowing strongly in certain directions may also further reduce predicted L.W. and H.W. levels.

4. CALCULATION OF TIMES AND HEIGHTS

(*a*) **The Admiralty Tide Tables (Home Waters Sec.A.)** give daily predicted times and heights of high and low water at all standard ports. Heights are always referred to the datum, and should be added to chart depths—unless preceded by an asterisk—in which case they are subtracted. Corrections to determine the height of tide at times between high and low water are obtained from the *Supplementary Table No.* 1. This is self-explanatory but does not apply between Swanage Bay and Selsey Bill (Sec. 3 (*d*) above). Times and heights of high and low water at numerous *secondary ports*, not shown in the tables, can be calculated by applying factors from a list of *Tidal Differences* to the values given for the nearest standard port.

(*b*) **The Commercial Nautical Almanacs** give daily tables for times and rises of high water at every principal port. As with the Admiralty Tide Tables, all times are in G.M.T., but here the time of low water is taken as approximately half the period between two consecutive high waters. To obtain the height above datum at low water one must first discover from the tables the heights of MHWS and MLWS. Thus the depth by which high water is below MHWS will be the same as that by which low water is *above* MLWS. Heights between low and high water can easily be computed on the assumption that the tide rises *approximately* 1/12th of the total range in the first hour of the flood, 2/12th in the second hour, 3/12th in the third, another 3/12th in the fourth, 2/12th in the fifth, and 1/12th in the sixth hour. It likewise ebbs at the same rate—1, 2, 3, 3, 2, 1. Time of high water at numerous secondary ports can be calculated from the time for Dover, by adding or subtracting a factor from a given list of *Tidal Constants*. Here again the rules do not apply in the case of double-day tides.

It has been shown in Sec. 3 (*e*) above that the times and heights of tides can be affected by strong winds or barometric pressure. If there is any doubt, it is, therefore, wise to assume it is spring tides when entering a port at or near low water. (There is always more water on a bar at LWN than at LWS).

5. LUNITIDAL INTERVALS

For any given place HWS and LWN always occur at nearly the same time of day in relation to solar or lunar time. Thus, if tide tables are not available, times and heights of high and low water can be determined very approximately providing the date of the nearest new or full moon is known, and the chart shows what is termed the *establishment* of the nearest port. This will indicate *lunitidal intervals*—or values for the high and low water *full-and-change* of the moon (HWF & C or LWF & C). If, for example, a port is tabulated with *HWF & C 7h. 9m.*—this means that high water there will be seven hours nine minutes after midnight on the day of the full moon, or seven hours nine minutes after mid-day on the day of the new moon. As the time of high water is roughly 50 minutes later each day, the approximate time at which it will occur can thus be easily determined for any day. The time of low water is likewise calculated with the LWF & C—but if this is not given, then six hours 12 minutes should be added to or subtracted from the time of high water.

To find the height of high water, it is necessary to subtract 1/7th. of the difference between MHWS and MHWN for each day that the predictions are from the springs, assuming these to occur one to two days after a new or full moon. On the other hand, to determine the height of low water on any day, it is merely necessary to subtract the height of high water from twice the height of mean level (the mean between the height of average high water and average low water).

6. SOUNDINGS

Depth of water can be measured by the following methods :

(*a*) **The Boat Lead Line.** This is made up from 12 fathoms (72 feet) of 2½ lb. line, with a 7 lb. lead sinker. The base of the latter should contain a hollow, which is filled—or *armed*—with tallow, and will thus indicate the nature of the sea bottom. It is also customary to mark the line by the following standard method, so that depths can be recognised in the dark by feel alone :

Up to	3 fathoms	Knots at every foot
At	2 fathoms	A piece of leather with two tails
At	3 fathoms	A piece of leather with three tails
At	5 fathoms	White bunting
At	7 fathoms	Red bunting
At	10 fathoms	A piece of leather with a hole in it

The depth of water is estimated in daylight by the position where the water cuts the line, when the lead is touching the sea bottom, and directly under the operator. At night it is necessary to ascertain first the distance of the operator's hand from the water—a factor known as *drift*. The depth of the water is then calculated by subtracting the latter from the nearest mark to the hand. It will be noted that the fathoms

4, 6, 8 and 9 are not marked on the line, and these are termed *deeps*. Thus the correct manner of calling soundings is as follows :

3 fathoms " By the Mark Three "
3¼ fathoms " And a Quarter Three "
3½ fathoms " And a Half Three "
3¾ fathoms " Quarter Less Four "
4 fathoms " Deep Four "

N.B.—If a line is being made up in the manner described above, it is essential to wet and stretch it thoroughly before marking.

(*b*) **The Hand Lead Line.** This comprises 25 fathoms (150 ft.) of 1⅛-inch line with a 10-14 lb. cylindrical-shaped lead, the base of which is slightly wider than the top. An eye at the end of the line is passed or rove through a becket and over the base of the lead and hauled taut. This line has the following markings in addition to those of the Boat Lead Line :

At 13 fathoms Blue bunting
At 15 fathoms White bunting
At 17 fathoms Red bunting
At 20 fathoms Two knots

(*c*) **The Sounding Machine.** This consists of a frame with a drum containing 300 fathoms of seven-strand galvanized steel wire, and controlled by a handle and brake. Passing over the ship's side via a sheave on a boom, the line ends with nine feet of special plaited hemp line, and a 24 lb. malleable iron sinker. It also has attached to it a metal guard containing a glass tube of red silver chromate, sealed at its upper end and open at the base. Sea water, acting against the internal air pressure, will turn the chromate white, and the depth will be proportional to the amount discoloured. By placing the tube against a provided boxwood scale, the correct sounding can be obtained. When the wire is running out, a metal bar—or *feeler*, is held against it to discover when the sinker touches the bottom. A dial on the top of the machine enables readings to be taken without tubes. They are used with correction tables based on speed, and are valuable as guides to shoaling, but must not be regarded as of high accuracy.

(*d*) **The Echo-Sounder.** This is a device which transmits super-sonic impulses, which are reflected from the sea bottom and return as echoes. The impulses are sent out by a transmitting oscillator, received by a hydrophone, amplified, rectified and recorded on starched-iodized paper. Based upon a standard speed of sound in sea water of 4,900 feet per second, the interval between transmission and reception is converted into a graphic presentation of depth, showing a series of recorded return echoes on a continuous " bottom " line. Providing the instrument is well serviced, corrected for distance of oscillators below water line, properly time checked and tested against an accurately marked lead-line, no better sounding instrument has yet been devised for the benefit of seamen.

Part II—ASTRONAVIGATION

CHAPTER VI

OBSERVATIONS

1. ASTRONAVIGATION

When out of sight of land, the mariner can obtain his position on the earth's surface by observations of celestial bodies. These include the Sun and Moon, the planets *Venus*, *Mars*, *Jupiter* and *Saturn*, and many different stars (p. 77). The following chapters will therefore set out to describe the taking and working of such observations, with a very brief explanation of elementary theory.

In the first place, it is necessary to imagine a hypothetical *Celestial Sphere*, surrounding and concentric with the earth, and on which the heavenly bodies appear. Its equivalents of latitude and longitude are known respectively as *Declination* and *Right Ascension*, and, owing to the easterly terrestrial rotation, it always appears to be turning westwards round the earth. The position on the earth immediately beneath a celestial body is called its *Sub-Stellar Point*, and the position in the celestial sphere vertically above a point on the earth below is called its *Zenith*. The location of a heavenly body can thus be described with the aid of its *Zenith Distance*, i.e., the angular distance from the observer's zenith. Another useful factor is the angular distance of a body westwards from the observer's meridian ; this is known as its *Hour-Angle*, and can be expressed in hours from 00 to 24, or degrees and minutes of arc from

0° to 360°. This correlation which enables longitudes and hour-angles to be given in time or arc is a basic principle of navigation, and has already been mentioned on p. 24. It will thus be appreciated that one hour is equivalent to 15°, or, conversely, 1° is equal to four minutes of time.

2. MEASUREMENT OF TIME

Time measurement involves the division of a day into hours, minutes and seconds, and a day is the interval between two successive transits of a celestial body across an observer's meridian. In this way, the various bodies give rise to different measurements of time :

(*a*) **Apparent Solar Time** (**AST**) is based on the passage of the true, visible sun ; but, as its movement is not uniform, it has been necessary to adopt another unit—

(*b*) **Mean Time** is derived from the *Mean Solar Day*, which is the average of all the *Apparent Solar Days* over a great number of years. It thus represents the movement of an imaginary *Mean Sun* of uniform speed. It is customary to use the *Greenwich Mean Time* (*GMT*) as a standard, and from this can be calculated the *Local Mean Time* (*LMT*) of any place, as on p. 24. Nevertheless in many calculations the navigator has to work in A.S.T., and thus converts the mean time with a factor known as the *Equation of Time*. The latter is obtained from the almanac, although in actual practice, a quantity *E* is more commonly used—having the value of 12 hours minus the equation of time. Added to the L.M.T., this gives the *Hour-Angle of the True Sun* (*HATS*).

(*c*) **Sidereal Time.** This is based on the interval between successive transits of a star, though, for convenience and accuracy, it is customary to use instead the *First Point of Aries* (*FPA or* ♈). This is the position where the path of the sun crosses the equator of the celestial sphere on March 21st, at the time of the spring equinox. *Local Sidereal Time* (*LST*) can be calculated by adding a factor *R* (tabulated in the almanac) to the LMT.

3. INSTRUMENTS

The essential equipment for astronavigation comprises a sextant, an accurate deck-watch, an almanac (Chap. VII) and a volume of the requisite tables.

(*a*) **The Deck-Watch** should be kept continuously working and *set to GMT*. When in use it should also be frequently checked—e.g., by B.B.C. time signals, and any error noted—so that observed times may be corrected and also the daily rate of error determined. Deck-watches should not be actually corrected unless the error becomes disproportionately large.

(*b*) **The Sextant.** In the marine sextant of fig. 9 *H* is a Horizon-Glass (half-silvered and half-plain), *I* is an Index Mirror pivoted on the arm *A*, and *T* is a Telescope or Plain Sight Tube. With such an instrument the elevation of a celestial body above the horizon can be determined by adjusting the angle of *I* so that an image of the body is visible in the mirrored half of *H*, level with the horizon viewed through the plain part. The required angle is shown by the pointer *P* which moves over a graduated arc comprising a sixth of a circle.

The scale is, however, marked from 0° to 120° because, when a ray of light is successively reflected by two mirrors in the same plane, the angle between the first and finally reflected rays is double the inclination of the mirrors. The degrees and minutes subtended are called the *Sextant Altitude*, and the exact time of the observation is noted from the deck-watch.

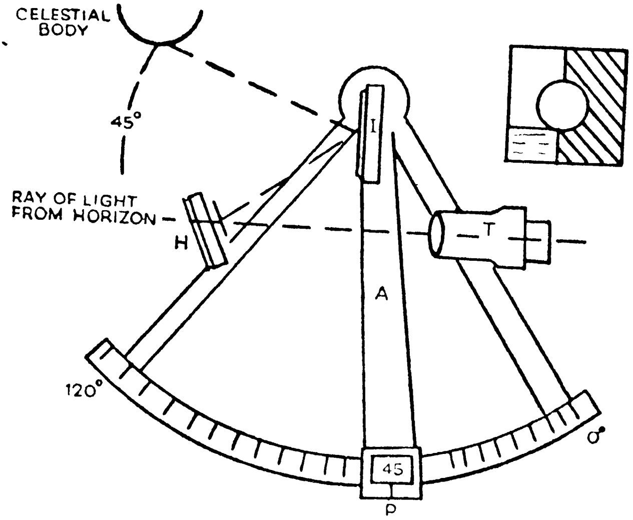


Fig. 9. The Marine Sextant
Inset shows the Horizon Glass with the sun's lower limb touching the horizon

Several errors can appear in a sextant, and should normally be only corrected by an expert. The most common one is the *index error*, which is present when the subtended angle is shown too high or too low. This error is found by aligning the horizon (observed directly) with its reflection, when the instrument is in the vertical plane, and noting the reading on or off the arc. The Index Error (minus if on the arc, and plus if off the arc) must always be applied to observed altitudes.

4. THE ASTRONOMICAL POSITION LINE

Briefly, the principle of a celestial observation is to obtain a position line by observing the altitude of a heavenly body (the angle at the observer's eye between the body and the horizontal), at a certain moment and from an assumed position (the D.R. position or a convenient point near it). At any given instant places on the earth where this observed altitude has the same value all lie on the circumference of a circle, the centre of which is the body's sub-stellar point. The navigator's position must therefore be somewhere on this *Observed Position Circle*, but the problem is to find its path. It is, however, possible to calculate from tables what would have been the altitude and azimuth (bearing) of the body if it had actually been observed in the position assumed—which must of consequence lie somewhere on a *Calculated Position Circle*. The difference between the calculated and observed altitudes is known as the *Intercept* and is the distance by which the observed position circle is nearer to or further from the sub-stellar point than the calculated position circle. It is thus possible to draw on the chart a line through the assumed position in the direction of the azimuth. The intercept—either *towards* or *away from* the body indicates a point on this line through which the observed position circle must pass. As the curvature of its circumference is very slight, a short arc may without appreciable error be indicated as a tangent or perpendicular to the azimuth line. This tangent is the *Astronomical Position Line.*

Note—The distance in arc from the observer to the sub-stellar point is the observed altitude subtracted from 90°—a factor known as the *True Zenith Distance.* For example, a navigator observing an altitude of 20° must be somewhere on the circumference of a circle whose centre is the sub-stellar point, and whose radius is (90°-20°) or 70° of arc, or 4,200 nautical miles. In the calculations of Chap. VII the intercept is found from the difference between the True Zenith Distance and the Calculated Zenith Distance (90°—Calculated Altitude).

5. CALCULATION OF OBSERVATIONS

It can be seen from the preceding section that a celestial observation involves certain calculations in order to obtain the Calculated Altitude (or Calculated Zenith Distance) of the body observed. These are

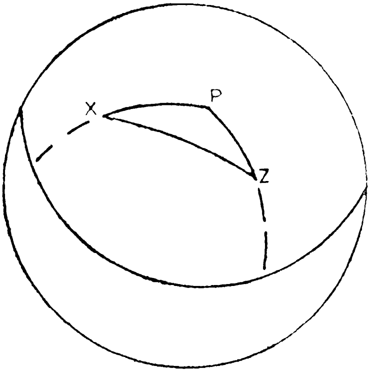


Fig. 10. The Spherical Triangle

based on the solution of the spherical triangle PZX of fig. 10 in which :

Z is the navigator's assumed position.
P is the nearer pole.
X is the sub-stellar point of the celestial body.

Therefore—

PZ is part of the observer's meridian termed his *Co-Latitude* (90°-Lat.).

PX is part of the body's meridian termed its *Co-Declination* (90°-Dec.).

ZX is the Great Circle through Z and X, termed the Zenith Distance or Co-Altitude of the celestial body (90°-altitude).

$Z\hat{P}X$ is the *Hour-Angle* of the celestial body. As explained on p. 67, this is always measured westward, thus its value will be 360°-H.A. if the body is East of the observer.

To solve the triangle, one must know either two sides and the included angle, or, alternatively, all three sides. The Co-Latitude and Co-Declination can readily be established from the D.R. latitude and the declinaation of the body, but the Hour-Angle $Z\hat{P}X$ must be computed from the data given in the almanac. The triangle can then be solved from the formula—

$$\text{Haversine } ZX = \text{Hav. } Z\hat{P}X \sin PZ \sin PX + \text{Hav. } (PZ \sim PX)$$

NOTE.—A *Haversine* is half of a *versine*, and the versine of an angle is equal to one minus the cosine of that angle. The symbol $\sim$ signifies addition with quantities of different signs, and subtraction if signs are alike. The *Altitude-*

Azimuth and *S.A.N. Tables* described in Chap. VIII are simply sets of tables containing already solved PZX triangles.

6. PLOTTING AN OBSERVATION

It can now be seen that a ship's position cannot be fixed from a single observation, which only gives an *intercept*. The use of this, however, is best explained in fig. 11, where a sunsight was taken at 1030 in the D.R. position *A*. The intercept was calculated to be *five miles towards* the sun, the true bearing of which was DUE EAST. *AX* is thus drawn for five miles in the direction EAST (though, if the intercept had been *away* from the sun, it would have been drawn WEST to *X'*). If *CXD* is now constructed through *X*, perpendicular to *XA*, then the vessel's position at 1030 must have been somewhere on *CXD*.

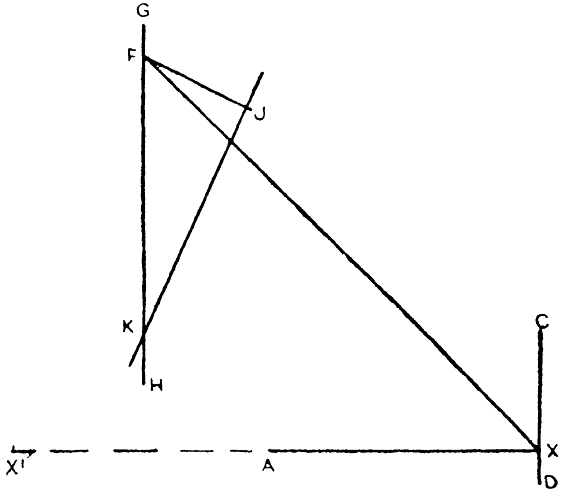


Fig. 11. THE OBSERVED POSITION

Another observation was taken at 1130, when the ship had steered ten miles NW. This course is represented by *XF*, and *GFH* is drawn through *F* parallel to *CD*. The intercept from this sight was *two miles towards* the sun (bearing ESE) as shown by the line *FJ*. If a line is now constructed through *J* perpendicular to *FJ*, then the point *K* where it cuts *GFH* is the ship's *Observed Position* at 1130.

The above method of observation is called a *Sun-run-Sun*, and the principle also applies to moonsights, which can be taken as a *Moon-run-Moon*. On the other hand, one sunsight can be combined with one moonsight to form a *Sun-run-Moon* or *Moon-run-Sun*. With stars and planets, observations are generally taken of two or more bodies at the same time ; this gives two or more position lines, and the ship can be fixed immediately without a run in between sights.

By two methods explained in Chap. IX, it is possible to calculate a vessel's latitude from a single observation. This entails a sight of :

(*a*) **POLARIS (The Pole Star)** which, for all practical purposes, appears constantly over the North Pole, or—

(*b*) **The Sun**, when it has ceased to rise, and is about to descend. It is then said to have reached its *meridian altitude*, and its true bearing will be DUE SOUTH (or DUE NORTH). More accurate than a *Sun-run-Sun*, it is thus preferable to take a *Sun-run-Mer. Alt.* The position lines resulting from all such meridian altitudes are practically parallels of latitude. It is also possible, as later explained, to take *Ex-Meridian observations*, when the sun is close to the meridian, but has been perhaps obscured at the time of the actual meridian passage.

7. Rules for Accurate Observations

(*a*) The most accurate positions result from the simultaneous altitudes of two or more heavenly bodies with position lines about 60° apart, and, if possible, two additional check observations on opposite azimuths in the case of two of the bodies. Such a set of observations can be taken well within ten minutes if preparation is made.

(*b*) At least an hour should elapse between two sights of the same body, and the angle of " cut " of the position lines should not be less than 30°.

(*c*) An altitude of less than 10° is of little value.

(*d*) In clear weather observations should be taken from the highest convenient position, but in poor visibility from the lowest.

(*e*) The sextant should be swung a few degrees on either side of the vertical, so that the celestial body appears to describe an arc. The observed altitude is measured at the point where this arc touches the horizon.

(*f*) At least three observations should be taken of each celestial body at one time, and the mean or most accurate reading used.

8. Stellar Observations

For accurate starsights it is essential to have a clearly defined horizon. The ideal time for observations is, therefore, at evening or morning twilight, and the positions and identities of the stars can be pre-determined with a Star Globe, Chart, Atlas or Identifier. An inexpensive and effective form of the latter is the "*Rude Star Finder and Identifier*," originated by Captain G. T. Rude of the U.S. Coast and Geodetic Survey. This comprises a star diagram and set of templates relative to different latitudes. The template for the appropriate latitude is placed on the diagram, so that it bears relation to the D.R. latitude and Local Sidereal Time (Local Mean Time + the factor *R* from the almanac). It is then possible to read off the required bearing and altitude of any star. Planets can be plotted from the co-ordinates for the appropriate day given in the almanac. Another compact but invaluable aid to star identification is the booklet published by the Admiralty Hydrographic Department entitled "*What Star Is It?*"

Following is a list of the most commonly used navigational stars. The figures in brackets indicate their magnitudes, or relative brightness, as given in *Eichelberger's Catalogue*:

Achernar (0.6)
Aldebaran (1.1)
Alpheratz (2.2)
Altair (0.9)
Antares (1.2)
Arcturus (0.2)
Bellatrix (1.7)
Betelgeuse (0.5-1.1)
Canopus (−0.9)
Capella (0.2)
Castor (1.6)
α Centauri (0.1)
β Centauri (0.9)
Deneb (1.3)
Dubhe (2.0)
Formalhaut (1.3)
Polaris (2.1)
Pollux (1.2)
Procyon (0.5)
Regulus (1.3)
Rigel (0.3)
Sirius (−1.6)
Spica (1.2)
Vega (0.1)

CHAPTER VII

CALCULATIONS WITH THE "R & E" ALMANAC

1. ALMANACS

From a sextant altitude and corresponding deck-watch time, an intercept for an observed position can be calculated by alternative methods, employing the two common types of almanac—

(*a*) The "R & E" almanac.*

(*b*) The "G.H.A." almanac.

This chapter will describe the use of the first type, which gives daily, and in some cases two-hourly positions of heavenly bodies in terms of *Right Ascension* and *Declination*, together with the two quantities defined as *R* and *E*. These are used in the calculation of observations by what is known as the *Marc St. Hilaire* (or *Haversine-Cosine*) *Method.* This requires also a volume of nautical tables—several versions of which are available, including the official American *Bowditch's Tables* (U.S. Navy publication *HO*.9) ; for the sake of convenience, however, the following example will refer to those edited by *S. M. Burton.*

---

* *The Abridged Nautical Almanac published by H.M. Stationery Office is at present in the " R & E " form but will be issued as a G.H.A. Almanac in* 1952.

2. MARC ST. HILAIRE SUNSIGHT CALCULATION

DR. longitude 20° 38′*E*
Date 4/3/46. 4
82*m*32*s*

(*a*) Correct the deck-watch time with deck-watch error, and thus obtain *GMT* of observation. To this apply *DR.* longitude difference (p. 24) and hence obtain the *LMT.*

(*b*) In the almanac look up the ephemeris headed SUN for the relative date and time, and note values for " *E* " and *Dec.*

(*c*) " *E* " is added to the *LMT*, and the sum called *Hour Angle True Sun* (*HATS*).

DWT	07	32	58
DWE			30 slow
GMT	07	33	28
LD	01	22	32
LMT	08	56	00
" *E* "	11	48	02
HATS	20	44	02

(*d*) If the *Dec.* and *DR.* latitude have the same signs, the former is subtracted from the latter, but if they are unlike they are added. In either case the result is termed the *L∽D.*

DR. lat.	34°10′*N*
Dec.	06°38′*S*
L∽D	40°48′

(*e*) The *HATS* is entered in the *Haversine Table* (No. 27 in " Burton ") under the column headed LOG. If its value is less than 12 hours, the hours and minutes are found at the head of the column, and the seconds under Time at the left-hand side. If the value is over 12 hours, the hours and minutes are taken from the bottom of the column, and the seconds from the right-hand side reading upwards. The result from this table is called the Log. Hav. Hats., and consists of a whole number (from the top of the readings) and five decimal places.

(*f*) The *Dec.* and *DR.* latitude are entered in the table of Logarithmic Functions, the degrees being found at the top of the pages, and the minutes down the left-hand side. The results—each likewise a whole number and five decimal places—are taken from the column headed Cos., and are called Log.Cos.Dec. and Log.Cos.Lat.

(*g*) Log.Hav.Hats., Log.Cos.Dec., and Log. Cos.Lat. are added together, and the first figure of the total deleted (e.g., 29.15012 becomes 9.15012). This value is then entered in the Log. column of the Haversine Table, and the corresponding quantity obtained from the Nat. column is called the Natural Haversine.

LOG.HAV.HATS.		9.23532
LOG.COS.DEC.		9.99708
LOG.COS.LAT.		9.91772
	(2)	9.15012
NAT.HAV.		0.14129

(*h*) The L∽D from (*d*) is entered in the Haversine Table, the degrees being found at the top of the column and the minutes from the ARC column on the left. If the minutes are less than 30, the result is obtained from the NAT column headed 00′; but if they exceed 30, then that amount is subtracted when referring to the ARC column, and the result is given under the 30′ NAT heading. In any case the result is termed HAV. L∽D.

(*i*) The NATURAL HAVERSINE of (*g*) is added to the HAV. L∽D, and the sum is called HAV. CZD. This is entered in the NAT column of the HAVERSINE TABLE, reversing the process of the above paragraph. The resultant value in degrees and minutes is known as the CALCULATED ZENITH DISTANCE (CZD).

NAT. HAV.	0.14129
HAV. L∽D	0.12150
HAV. CZD	0.26279

CZD 61° 40½′

(*j*) The index error is applied to the sextant altitude, and the result is termed the OBSERVED ALTITUDE (OA).

SA	28° 22′	
IE	6	*high*
OA	28° 16′	
TC	00 11	
TA	28° 27′	

(*k*) TOTAL CORRECTIONS for the height of the observer's eye, and the month of the year are obtained from Table 12 in " Burton ", and are added to the OA, giving a resultant

TRUE ALTITUDE (TA).

(*l*) The TA is subtracted from 90° and the difference called the TRUE ZENITH DISTANCE (TZD).

	90° 00′
TA	28° 27′
TZD	61° 33′

(*m*) The difference in minutes between the TZD and CZD is the required *Intercept* in miles. If the TZD is greater, the Intercept is *away* from the sun, but if the CZD is greater it is *towards* the sun.

CZD	61° 40½′
TZD	61° 33′
I	7½ *miles* *TOWARDS*

(*n*) The sun's true bearing can be calculated from :

1. Tables which give the azimuth directly from inspection.
2. " ABC " Tables (Numbers 33 and 34 in " Burton ").
3. Weir's Azimuth Diagram, as explained on p. 24.

It is also possible to take a direct bearing of the sun with a compass at the time of the observation. This, however, is liable to facilitate errors and is quite unnecessary as precise values can easily be computed.

3. CALCULATION OF A MOON, STAR OR PLANET SIGHT

(*a*) Calculate the Local Mean Time as above.

(*b*) In the almanac, under the astronomical ephemeris headed SUN, determine the appropriate value for *R*. Add this factor to the LMT, and call the sum the *Local Sidereal Time* (*LST*).

(*c*) From the LST subtract the factor *RA* (*Right Ascension*) found in the almanac under the relative heavenly body. Its value is generally given hourly for the moon, daily for planets, and monthly for stars. Interpolation is, therefore, necessary. The difference between the LST and RA is called the *Hour-Angle* (*HA*).

(*d*) Thence proceed as for a sunsight, except that the Declination used must be that given for the required heavenly body ; also the Total Corrections to the Observed Altitude must be taken from the moon or star correction tables in the nautical tables.

Chapter VIII

CALCULATIONS WITH THE "G.H.A." ALMANAC

1. The Greenwich Hour Angle

The " G.H.A. " almanac gives values for *Declination* and an angular quantity known as the *Greenwich Hour-Angle* (*G.H.A.*). For the sun this is a combination of the G.M.T. and Equation of Time, but for other bodies it combines the G.M.T., the Right Ascension of the Mean Sun, and the Right Ascension of the body. The almanac thus tabulates the G.H.A. of each body as follows :

(*a*) **The Sun.** A corresponding value for every hour of G.M.T. is given in the daily Sun tables, under the column headed " G.H.A. of Sun."

(*b*) **The Moon.** Values for every 12 hours G.M.T. are given in separate tables for the moon.

(*c*) **The Stars.** A corresponding value for every even hour of G.M.T. is given in the daily Sun tables under the column headed " G.H.A. of F.P.A. " (or " G.H.A. of ♈). To this is added the *Sidereal Hour-Angle* of the appropriate star, which is given in separate tables of monthly values.

(*d*) **The Planets.** Daily values are given in tables for each of the planets.

N.B.—In all cases, interpolation necessitates the use of special " Correction Tables."

Calculations with this type of almanac do not take the ship's D.R. as a basis, but use a position adjacent to it, where the latitude is a whole number of degrees, and the longitude has been adjusted to combine with the G.H.A. in forming a *Local Hour-Angle*, which must also be a whole number of degrees.

For example, if D.R. latitude is 51° 27′N then 51° is taken in lieu.
Likewise, if D.R. longitude = 02° 35′W and G.H.A. = 58° 32′
Then the *Assumed Longitude* becomes 02° 32′
So that the *Local Hour Angle* is 56° 00′
If, however, D.R. longitude had been 02° 35′E and G.H.A. still 58° 32′
Then the Assumed Longitude would now become 02° 28′
And the Local Hour Angle 61° 00′

2. CALCULATION OF OBSERVATIONS

The Assumed Latitude, Declination and L.H.A. having been determined, there are now two systems of calculating the observation of any heavenly body, which are found in common use :

(*a*) **The Altitude-Azimuth Method.** This involves the use of *Astronomical Navigation Tables* (Air Publication 1618), which are now issued by H.M. Stationery Office, in a number of volumes covering latitudes from S79 to N79. Alternatively, the U.S. Navy publication *HO*.214 covers 10° belts of latitude, tabulated for every half-degree of declination. In the section containing the correct latitude, the L.H.A. is applied to the relevant DEC. column, taken to the nearest 30′ and selected according to whether the declination and latitude have similar or unlike signs. From this table are obtained the *Tabulated Altitude*, *Azimuth* (i.e., true bearing of the body), and a fraction with the letter *d* as numerator—e.g., $\frac{d}{-42}$. This is the *increment* for odd minutes of declination, and by entering it in a table at the end of the book, a correction to the tabulated altitude is obtained. Application of this correction gives the *Calculated Altitude.*

(*b*) **The " S.A.N. " Method.** This requires only one volume of " *Sea and Air Navigation Tables* " (compiled by Dr. L. J. Comrie), or their American counterpart—Dreisonstock's " *Navigation Tables for Mariners and Aviators* " (*HO.* 208). " S.A.N. " comprises three principal tables, and " Dreisonstock " two. Both systems are almost identical and commence with entering the L.H.A. and Assumed Latitude in Table I. In the U.S. version, this gives values for the letters b, A, C and Z'.

If the declination and b have like signs they are added, but, if unlike, the smaller is subtracted from the larger. In any case, the result is called $d \backsim b$, and applied to Table II which gives values for B and D. B is added to A, and D to C.

$A + B$ is entered in column B of Table II, which gives the Calculated Altitude (degrees at the top, minutes on the left).

$C + D$ is entered in column D of Table II, which gives a value for Z'' (degrees at the top, tenths of a degree on the right).

The sum of $Z' + Z''$ is the required Azimuth. By both methods (*a*) and (*b*) the True Altitude is obtained directly by inspection and interpolation, and the difference in minutes between it and the Calculated Altitude is the Intercept from the Assumed Position in miles. Here, however, the Intercept is *towards* the heavenly body if the T.A. is greater, and *away* from it if the C.A. is greater.

Below is an example of the two G.H.A. methods applied to a sunsight taken in D.R. position 34° 10′ N, 20° 38′ E on 4/3/46.

DWT	07	32	58	
DWE			30 slow	
GMT	07	33	28	
GHA		289° 53′		Dec 6° 38′S
Assumed Long.		20° 07′		
LHA		310° 00′		

Altitude-Azimuth

Tabulated Alt. 28° 10′ (*d*) *Az.* 120

−42

Correction 27′

Calculated Alt. 27° 43′

Dreisonstock

Dec 6° 38′ S

b 43° 37′N

d∼*b* 36° 59′

A	11213	*C*	197	*Z′*	56.3
B	22070	*D*	123	*Z″*	64.4
A+*B*	33283	*C*+*D*	320	*Az*	120.7

Calculated Altitude = 27° 41′

SA	28° 22′
IE	6′
OA	28° 16′
TC	11′
TA	28° 27′

INTERCEPT = 44 *miles towards.*

INTERCEPT = 46 *miles towards.*

Thus the factors to be plotted on the chart are as follows :

Assumed Latitude	34°*N*
Assumed Longitude	20° 07′*E*
Intercept	44 *or* 46 *miles towards*
Bearing of Position Line	120° *or* 120.7°.

CHAPTER IX

SPECIAL OBSERVATIONS

1. THE POLE STAR

POLARIS, or the Pole Star, is, as already explained, of the greatest use to the navigator, as at any time during a clear night a single observation will give a correct latitude. In twilight, however, the star is frequently invisible to the naked eye, and it is therefore customary to clamp the index of the sextant to the D.R. latitude and sweep the horizon to the North so that POLARIS will be easily located.

An observation is taken as for any other star, and the Deck-Watch Time (D.W.T.) is converted with Deck-Watch Error (D.W.E.), Longitude Difference and *R* to form the Local Sidereal Time (L.S.T.). Likewise, the sextant altitude is corrected with the index error and total correction (always *subtractive* for a star) to give the True Altitude.

The three* *Pole Star Tables* are then used from the almanac. To the first is applied the L.S.T., to the second the L.S.T. and True Altitude, and to the third the L.S.T. and date. From these tables are thus obtained three corrections which are added to, or subtracted from the True Altitude. The resultant value is the vessel's latitude.

---

* Reed's Nautical Almanac *only publishes one table, to which is applied the L.S.T. and T.A.*

Example—

GMT	06 53 30	*True Altitude*		46° 17.2′
Long.	04 16 00	*Correction from Table*	*I*	41.6′
LMT	02 37 30	,, ,, ,,	*II*	0.3′
R	14 11 42	,, ,, ,,	*III*	−0.1′
LST	16 49 12	*Latitude*		46°59′

(*Date* 25/4/45).

2. THE MERIDIAN ALTITUDE

When taking an observation of the Meridian Altitude (page 75) it is necessary first to determine the time at which it will occur. This is achieved by subtracting the appropriate value for *E* (p. 24) from 24.00 hours, and then applying the D.R. longitude difference (additive if East, and subtractive if West). This will give the required G.M.T. and a few seconds beforehand the sextant should be aligned on the sun. By adjusting the instrument, it is thus possible to ascertain the sextant altitude when the sun ceases to rise.

As in any other observation, the index error and sun or stars total correction are applied to the observed sextant altitude to obtain a true altitude, and this, in its turn is subtracted from 90° to give the True Zenith Distance (TZD). If the appropriate Declination is now applied to the TZD, the result will be the ship's latitude. When the sun is bearing SOUTH a Northern Declination is additive, or a Southern Declination subtractive.

Example—	*SA*	61 09 20		90 00 00
	IE	10	*TA*	61 07 30
	OA	61 09 10	*TZD*	28 52 30
	TC	1 40	*DEC*	08 24 30
	TA	61 07 30	*LAT*	37 17 00

3. THE EX-MERIDIAN ALTITUDE

Ex-Meridian observations are those taken with the sun close to the meridian, when perhaps clouds have obscured it at meridian passage. In such a case, it is necessary to take a Sextant Altitude and Deck-Watch Time as for a normal sunsight. A *reduction*, or small correction, is then obtained, which by addition converts the True Altitude to the value for " Mer. Alt. " The latitude is then computed as in the above paragraph.

The reduction can be calculated in two ways :

(*a*) By the formula—*Reduction in minutes* = $\frac{T^2}{K}$ where T is the number of minutes between the time of the observation and that of meridian passage, and $K = 30.6\ (\tan \mathrm{Lat.} \pm \tan \mathrm{Dec.})$. The tangents are added if the latitude and declination have opposite names and subtracted if they have the same names.

(*b*) The Deck-Watch Time is converted with the Deck-Watch Error, Longitude Difference and *E* to H.A.T.S. Then the latitude, declination and H.A.T.S. are applied to the *Ex-Meridian* section of the Nautical Tables, from which the reduction is obtained.

CHAPTER X

ORIENTATION

Following are a few very rough methods of orientation, etc., which should only be employed in the complete absence of navigational equipment :

1. THE SUN

(*a*) True bearings of sunrise and sunset can be found in the tables at the end of this book.

(*b*) If a watch is held face upwards, with the hour hand pointing towards the sun, then (in the Northern hemisphere) DUE SOUTH will lie *approximately* in a direction half-way between the hour-hand and twelve o'clock. Allowance must be made for Summer Time, etc., if in force.

(*c*) The approximate latitude can be determined as follows, with the aid of a compass, protractor, pencil and paper :

Take bearings of the sun with the compass, and when it appears at true SOUTH, hold the protractor upright and directed towards the sun, on the paper in line with the horizon. Place the point of the pencil at the centre of the protractor's edge on the paper, and elevate the other end pointed at the sun, until no shadow is cast before or behind it.

Read off the degrees the pencil touches on the protractor, and subtract them from 90°, calling the difference the *Zenith Distance* (*ZD*). The latter is applied to the day's Declination value, obtained from the DEC column in the table at the end of this book, and the latitude is thus calculated by adding the ZD to the DEC if the latter is North, or subtracting DEC from ZD if it is South. The system as explained here is, however, only suitable for latitudes above 23½°N.

2. The Moon

The following laws apply in the Northern hemisphere :

(*a*) In its first quarter (◗) the moon is South at 6 p.m.

(*b*) In its third quarter (◖) the moon is South at 6 p.m.

(*c*) The full moon is South at midnight.

3. The Stars

(*a*) The use of Polaris has already been explained in the previous chapter.

(*b*) It is possible to tell the approximate time with the aid of Polaris and Caph. The latter is the right-hand star of the Cassiopeia constellation, and will be found on the Star Identifier immediately next to Schedar.

Polaris is taken as the centre of an imaginary clock-face, as in fig. 12. The nearest number to the position of Caph is then added to the figure adjacent to the relative month. If the sum exceeds 12, then that amount

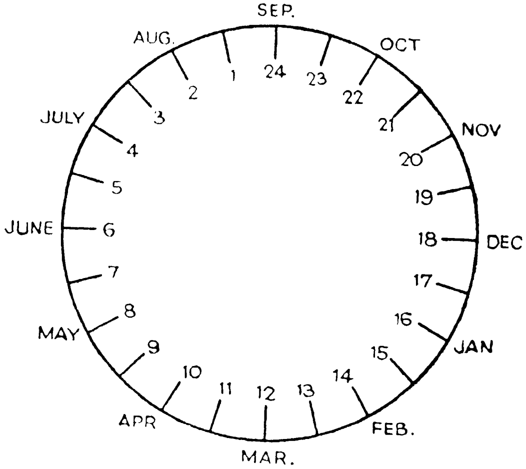


Fig. 12. Chart for Calculating the Time from the Stars

—or a multiple of it—is subtracted, and the result is the required time.

Part III — RADIONAVIGATION

It should be emphatically stated that the Radio and Radar devices described herein are only aids, and that the Rule of the Road has not been modified to include other than visual or aural indications, and the actions to be deduced therefrom to prevent collision. Such aids in their present state should confirm courses of action but not determine them by themselves. Thus fundamental navigational principles must always guide the navigator, and a complex which relies on electronics without confirmation is a menace.

CHAPTER XI

RADIO AIDS

1. M.F./D.F.

The oldest form of radio aid to navigation, which has been in existence since about 1906 is the system of *Medium-Frequency Wireless Direction-Finding* (*M.F./D.F.*). The principle of this consists of taking bearings of one or more different wireless stations of known geographical positions, and using the results as in a normal fix or running-fix. A common method employs a receiver with a loop aerial, and the required bearings are found by noting from which direction an incoming signal is received most weakly. Thus to utilise M.F./D.F., a ship can either—

(*a*) Take bearings of known shore transmitting stations or beacons or

(*b*) Transmit a signal, and obtain a report of its bearing from a known shore station.

2. ERRORS

The errors to which a M.F./D.F. installation is subject can be classified as follows :

(*a*) **Ionospheric Waves.** A Loop D.F. system can give quite misleading information owing to the presence of wireless waves reflected from the upper atmosphere. This limits the range between transmitter and receiver to 2-45 miles.

(*b*) **Coastal Deviation or " Shore Effect."** Wireless waves are bent from their normal path when they pass from one medium to another ; and a difference in the surface beneath them, or even a rise of tide may cause such a change in medium. The velocity of a wave over the sea may be up to 5 per cent. greater than over land, and high land especially may cause inaccuracy due to reflection. Reference should, therefore, be made to a chart, when there is any doubt about such errors.

(*c*) **Ship Deviation.** Errors may also be due to alternating currents induced in the metal parts of a ship. These cause subsidiary inductive magnetic fields, but can generally be counteracted by correctors. A *D.F.* unit requires calibrating in the same way as a compass needs swinging.

(*d*) **Natural Deviation.** Errors are very liable to occur between one hour before, and one hour after sunrise or sunset. It is thus advisable to refrain from taking bearings during these times.

(*e*) **Convergency.** Owing to the spherical shape of the earth, the meridians of longitude converge towards the Poles, and a wireless wave will intersect them at varying angles. This angular difference is known as the *convergency* of the meridians.

Convergency in minutes = D. Long. in minutes x sin. Mid. Latitude (page 38).

As it has already been explained, however, the meridians on a Mercator's chart are represented by parallel vertical lines, and thus the true wireless bearing of a ship cannot be represented directly as a straight line joining the ship and shore station. Such a line is called a *Mercatorial Bearing*, and differs from the true bearing by plus or minus half the convergency. The value for half convergency can be determined from a *D.F. Bearing Conversion Table*, and, when the bearing is taken by the shore station, the correction is applied according to the following rule :

In Northern latitudes, when the vessel is	East *of the station, correction is*	Added
	West	Subtracted
In Southern latitudes, when the vessel is	East *of the station, correction is*	Subtracted
	West	Added

If the bearing is taken by the ship, the above signs are reversed. Mercatorial bearings obtained in this way from two or more M.F./D.F. bearings can be plotted on a chart and used to fix the ship's position in the usual manner. When the ship and shore station are on opposite sides of the equator, convergency is virtually negligible, and such correction is unnecessary.

3. Procedure

(*a*) Call-Signs and Wavelengths of D.F. stations can be found in the *Admiralty List of Radio Signals.*

(*b*) Many D.F. stations will transmit signals for one minute, on receipt of the abbreviation *QTG*, so that bearings can be taken by installations in ships.

(*c*) To have its bearing reported to it, a ship should call the D.F. station on its listening wave, and send the abbreviation *QTE* ? (indicating if necessary the wavelength it proposes to use). On being invited to transmit, it should send its call-sign, with any other signal needed, for a sufficient time to enable the bearing to be taken. The D.F. station then replies with the abbreviation *QTE*, the *true* bearing of the ship *from* the station, the time of the observation, and the position of the station if it is mobile (preceded in this case by the abbreviation *QTH*). The ship must then repeat back the message received, and, if satisfied, the D.F. station signals " end of work."

4. RADIOBEACONS

These are aids to navigation, which, for the most part, transmit signals at fixed times daily in clear weather, increasing to a continuous service in periods of fog or low visibility. They are now installed throughout the world in two main forms :

(*a*) **Flashing Radiobeacons.** These are generally assembled in groups of three, with each transmitting for two minutes in sequence over a six-minute period. Transmissions are at 30-minute intervals, with staggered times of emission from the various groups. The frequency is in the band of 290-320 kc./s., which is divided into ten channels with a separation of 3 kc./s.

(*b*) **Rotating Loop Beacons.** Consisting of a medium-wave radio beam, rotating at a uniform speed, these make direction-finding possible without special shipborne apparatus, as they cause a rise and fall in signal strength in any standard receiver. When using this method, it is first necessary to note the period of the signal in seconds, and, as the beacon revolves through 360°, the rate of rotation must be $\frac{360^\circ}{\textit{period}}$ per sec.

If zero reception is found to occur z seconds after the commencement of the signal, then the bearing of the transmitter is $\frac{360z^\circ}{period}$ or $\frac{360z}{period} + 180^\circ$.

5. Synchronized Radio and Sound Signals

With some beacons an automatic submarine or air signal is synchronized with the radio transmission ; thus the distance from the source of sound can be determined from the time lag between the reception of the wireless and sound signals (in the case of subaqueous signals this entails the use of hydrophone gear). The bearing is as indicated by the D.F. unit and the distance in miles is approximately equal to *time lag x* 0.8 (submarine) or *time lag x* 0.18 (air). It should be observed, however, that the velocity of sound in air and water varies with temperature and salinity, etc.

6. Consol

Developed from the German *Sonne*, this navigational aid comprises groups of automatic beacons supplying a medium-frequency, continuous-wave transmission, with a total power of 1.5 kW. to three vertical aerials, spaced in line approximately 1.8 miles apart. The beacon has a range of about 1,200 nautical miles by day, and 1,700 by night. It emits dot-and-dash signals, which are picked up on a standard wireless receiver. A count is made of the dots and dashes heard during a transmission cycle of half or one minute, and, by applying the result to a chart overprinted with a *Consol lattice*, it is possible to obtain a position line.

Existing stations and their frequencies are :

Stavanger, Norway	319 kc./s.
Lugo, Spain	303 kc./s.
Seville, Spain	311 kc./s.
Bushmills, N. Ireland	263 kc./s.

7. Chart Abbreviations

The following abbreviations are used on charts to indicate radio aids to navigation :

Ro.	Coast Radio Station, which transmits a signal for D.F. purposes on request.	
Ro. Bn.	Radiobeacon.	
Ro. Loop.	Rotating Loop Radiobeacon.	
A.R.	Air Radiobeacon	See Chap. XIV.
R.R.	Radio Range	

CHAPTER XII

RADAR-ASSISTED NAVIGATION

1. PRIMARY RADAR

Broadly speaking, the principle of radar lies in transmitting pulses of wireless waves, which, on striking a target, are reflected back to a receiver. Simultaneously the time interval between transmission and reception is measured and converted into a range, which is shown on a " Display Unit "—e.g., a Cathode Ray Tube (C.R.T.).

Figure 13 shows a block diagram of a marine navigational radar set, working on a wavelength of

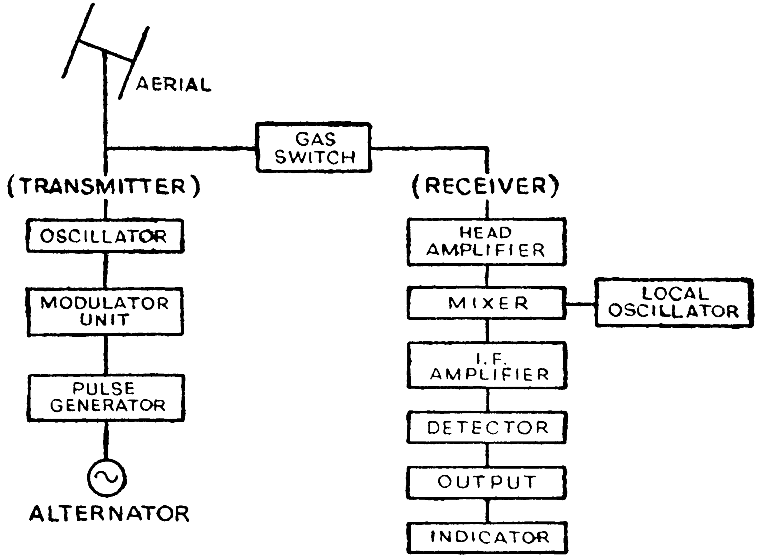


Fig. 13. BLOCK DIAGRAM OF PRIMARY RADAR

3 cm., and with a power consumption of 3½ kW. In the transmitter the *Pulse Generator* changes alternating current into a series of short pulses, which are fed to the *Modulator.* Acting as a switch, the latter allows only short bursts of High Tension to reach the Oscillator, which, in its turn produces corresponding short bursts of High Frequency waves. These are passed to the aerial via a metal tube—or *Waveguide.*

The directional aerial is housed in a "cheese-shaped" reflector, 5 ft. long and 3 ins. high, rotated by a ½ h.p. motor at between 20-70 r.p.m. The resultant beam width is 3° in the horizontal and 40° in the vertical plane. One single aerial is used for transmitting the pulse and receiving the echo. To prevent it being damaged, it is therefore necessary for the receiver to be isolated while the transmitter is operating. For this purpose a special valve is used, known as a *Gas-Switch,* which presents a high resistance to a large voltage and a small resistance to a low voltage.

The receiver is of the superheterodyne type, whereby the returning 3 cm. (10,000 kc./s.) signal is magnified in the *Head Amplifier,* and then mixed with a locally generated oscillation to form a constant and much lower *Intermediate Frequency* (*I.F.*). The rest of the receiver is similar to a normal broadcast circuit, and the I.F. is amplified, detected and fed via an Output Amplifier to an *Indicator Unit.* The two main controls of the receiver are the *Gain Control*—similar to an ordinary volume control, and the *Local Oscillator Control,* which adjusts the L.O. frequency in case it should not accurately " beat " with the incoming signal to form the I.F.

The Indicator Unit consists of a *Time Base Unit* (*T.B.U.*), which produces a visual representation of the echo on a Cathode Ray Tube. The T.B.U. is fired by a short pulse from the Pulse Generator or Modulator Unit. This is termed the *Sync. Pulse*, and is fed to the T.B.U. via the *Sync. Lead.* The C.R.T. is now commonly incorporated into a circular *Plan Position Indicator* (*P.P.I.*), on which the radar " beam " appears to rotate in synchronisation with the aerial. Objects in the path of the beam are shown as patches of light, and by means of a delaying " after-glow " effect a plan of the whole area surrounding the ship is retained. The unit has three range scales with maxima of 2,000, 15,000 and 45,000 yards, and an accuracy of about 50 yards. Bearings are reliable to approximately 1°, and a compass repeater (gyro or ATMC) is often incorporated. The indicator controls include *Focus*, *Brillance*, *Range Rings*—concentric rings which can be made to appear on the trace, *Heading Marker*—which makes a line of light appear corresponding to the ship's heading, *Swept Gain*—which magnifies distant echoes and reduces " sea clutter," and *Open Centre*—which expands the distance between echoes for close navigation.

The P.P.I. shows ships, etc., as bright spots of light, and the coast as a continuous outline ; its navigational value can, therefore, be appreciated for conning in fog or darkness. To this end, radar identification of buoys is assisted in some harbour approaches by fitting them with *corner reflectors* (fig. 14). The simplest type is a right tetrahedron with its equilateral surface removed—i.e., the shape obtained by cutting the corner off a hollow cube. A remote display unit from the main set can be installed in the chart-house, in the form of a

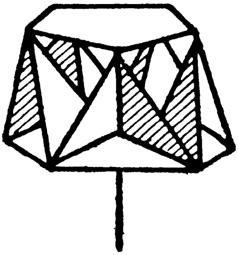


Fig. 14. CORNER REFLECTOR

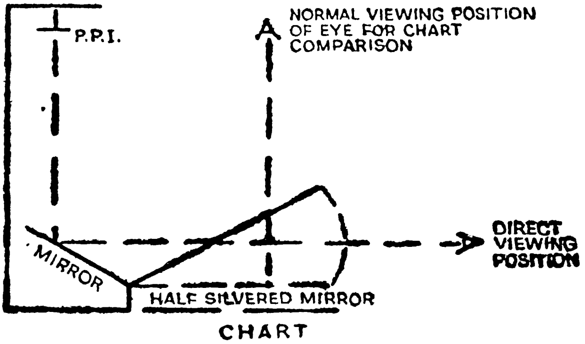


Fig. 15. CHART COMPARISON UNIT

Chart Comparison Unit (fig. 15). Here an arrangement of mirrors, one of which is half-silvered, enables a P.P.I. " picture " to be viewed superimposed on a navigational chart of the same scale. Modified Admiralty charts are generally used, with special colours, and contours, so that fixed points on them can be compared with radar " echoes." This unit has two ranges of 2,000 and 70,000 yards.

2. SECONDARY RADAR

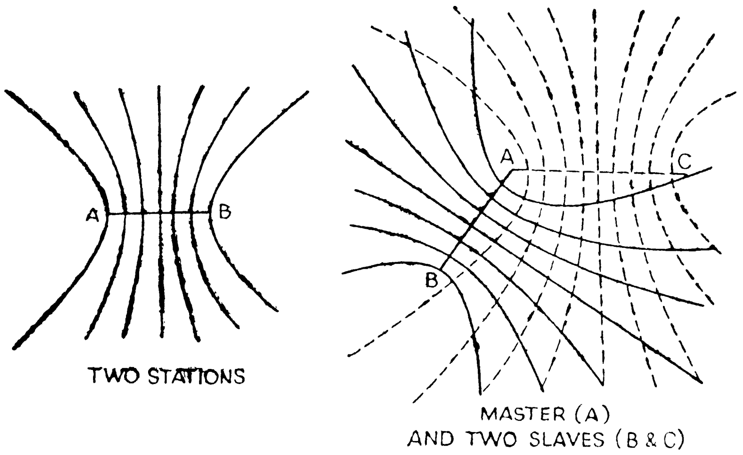
The use of radar in a secondary form is found in the *Racon*, or radar beacon. This is a device which picks up radar transmissions from a ship, and then with minimum delay emits a responding pulse, or number of closely-spaced pulses. The existing systems used with 3 cm. radar are :

(*a*) **Type 952.** The British Admiralty pattern racon consists of a receiver covering 9,320-9,600 mc./s., and a transmitter working on 182 mc./s. It has three response codes, and can respond to six ships at less than four miles, and 50 ships for greater ranges. The necessary shipborne equipment for using this device is a 182 mc./s. receiver, with an omni-directional aerial, fitted to the radar installation, so that response signals appear as a number of concentric arcs on the P.P.I The centre of the arc corresponds to the bearing of the beacon, and the nearest arc is greater than the true range by a fixed distance due to time-lag. This amounts to + 400 yards at minimum range.

(*b*) **Type AN/CPN-6.** The U.S. equipment comprises a superheterodyne receiver, covering 9,320-9,430 mc./s., and a transmitter with a frequency of 9,310 mc./s., and 60 response codes. The same principle is employed as in Type 952, though the equipment is much more cumbersome. Its traffic-handling capacity is 12 ships at ranges less than four miles, and up to 100 ships at greater ranges. However, whereas the British system endeavours to reply to all radar sets in the vicinity, this type only responds to sets with their pulse-length switched to two microseconds. The fixed delay varies with individual sets from 650 to 1,350 yards. The range of both beacons is approximately the optical range between the aerials.

3. Pulsed Position-Fixing

If two wireless stations, *A* and *B* emit pulses of radio waves simultaneously, or with a known interval, it is possible for an observer to calculate his position line relative to the stations, by measuring the time difference in the reception of their signals. Lines of constant time difference take the form of *confocal hyperbolae* (fig. 16), and can thus be pre-computed. If the time difference is also measured between the signals of *A* and those of a third synchronised station *C*, it follows that a fix can be



TWO STATIONS

MASTER (A) AND TWO SLAVES (B & C)

Fig. 16. Hyperbolic Lines of Constant Time—or Phase-Difference

found on one of a series of intersecting hyperbolae. Under these conditions, *A* is termed the *Master* station, while *B* and *C* are *Slaves.*

The two main systems of this type are :

(*a*) **Gee.** Here *chains* of one master and two or three slaves, sited up to 80 miles apart, emit a continuous series of radio pulses on frequencies of between 20-85 mc./s., and with a range of about 150 miles. The shipborne equipment consists of a Receiver Unit, and Indicator Unit. The latter contains a Cathode Ray Tube, wherein the time interval in the station reception is shown as the distance between vertical "blips" appearing on two horizontal *traces* (fig. 17)*. Generally there are four blips—*A* and *B* on the top trace, with *A's Ghost* and *C* on the bottom. From their positions it is possible to obtain two scale readings—each a whole number and two decimal places—which, in their turn, are applied to a *Lattice Chart.* This is based on a Mercator projection, overprinted with coloured and numbered hyperbolic curves

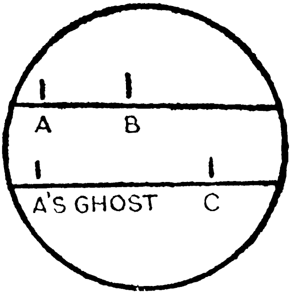


Fig. 17. The C.R.T. Indicator Unit

---

* *More recently developed is an electronic computor for automatically converting the readings into range and bearing from any point within the coverage of the chain.*

(*AB* red, *AC* green, *AD* purple). The obtained readings are thus plotted in relation to the curves, and the ship's position can be determined. Separate chart series are issued for each chain of stations.

(*b*) **Loran.** This is a long-range American counterpart of Gee, employing pairs of pulse-transmitting ground stations, separated by 200-400 nautical miles. The system utilises a frequency of about 1,900 kc./s., and has a range of 700 miles by day, and up to 1,400 miles by night. Stations are identified by characteristic recurrence rates, and a double-pulsed master can be common to two slaves ; thus chains are formed with all stations double-pulsed except the end ones. In the *DAS*-3 shipborne Indicator Unit the master blip appears on the top trace, and the slave on the lower one. The scale readings for such a pair can be converted into a single position line, and hence it follows that two pairs are required for a fix. The values are actually transposed with either a gridded chart or, alternatively, a set of tables (U.S. Navy publications *HO*.221, 221*a* and 221*b*). With the aid of these, position lines can be plotted directly on to the navigating chart.

A low-frequency form of the standard Loran, working at about 180 kc./s., has been found to operate over ranges of 1,500 miles by day, and 3,000 miles by night ; while a short-range adaptation of this system (*Shoran*) has shown an accuracy of 25 feet.

4. Phase-Comparison Position-Fixing

As opposed to the pulsed time signals used above, another form of navigational aid uses continuous or modulated continuous waves. The time-lag in transit is now determined by comparing the phase difference of the signals. Just as before, however, lines of equal phase difference form confocal hyperbolae. The main system of this type is the *Decca Navigator.*

In the case of *Decca,* a master and two or three slaves transmit steady continuous waves, which are accurately locked together in phase, and, as already mentioned, an observer's position is found by measuring phase differences, and plotting them on a chart overprinted with a numbered lattice. The English chain, at present in operation, has the following stations and frequencies :

PUCKERIDGE	*A*	Master	85 kc./s.
NORWICH	*B*	(Red) Slave	113.3 kc./s.
LEWES	*C*	(Green) Slave	127.5 kc./s.
WARWICK	*D*	(Purple) Slave	70.83 kc./s.

The shipborne instrument, which operates on all standard voltages, consists of a Receiver Unit, to which is connected a remote Indicator Unit, sited in the chart-house or bridge. The *Marine Mk. IV Receiver* is suitable for one chain only, and the Indicator Unit is fitted with three *Decometers* or phase-meter dials (*AB* red, *AC* green, *AD* purple). When the vessel is operating in the service area of a chain, it is merely necessary to plot its initial known position on a *Decca* chart, and apply the lattice co-ordinates for that position to the appropriate two decometer dials. Thereafter, they will constantly register the current co-ordinates, which need only to be read off and plotted back on to the chart.

The *Marine Mk. V Receiver* embodies multi-chain working, and one can, for example, change from the

English to the Danish chain simply by turning a knob on the right-hand side of the Receiver Unit. A *Lane Identification* system is also included, and entails a fourth meter on the Indicator Unit. This shows in turn the Red, Green and Purple Lane number of the vessel's position, each indication remaining set for five seconds. When entering the operational area of a chain, it is thus possible to have continuous and automatic position-fixing information as soon as the receiver is switched on.

Decca gridded charts, which can be obtained from Admiralty chart agents, cannot be kept up to date with corrections from ordinary Notices to Mariners. They must, therefore, be only used in addition to the navigational charts. When issued they show in black type the date of publication of the *basic* chart, with any large corrections and the number of the last Notice to Mariners for which it is corrected. The date of publication of the Decca chart is shown in the colour used for the primary series of curves (normally red), and small corrections affecting the Decca chart only are similarly recorded. In the catalogue Decca chart numbers are distinguished with the letter *L* and *Decca* in brackets.

The latest development in displaying the data derived from the equipment is automatic presentation of position on specially prepared maps, drawn with Decca co-ordinates as straight lines at right angles to each other. The desired course, with safe excursions on either side, is printed on these maps, and the actual course made good is overdrawn by a stylus operated by the instrument. The navigator thus has an instantaneous indication of his position and record of the trip. In an alternative arrangement the distance along the course can be displayed on a Veeder type counter and the distance off the course on a meter with central zero. Prototype models of both these equipments have been successfully demonstrated.

5. Chart Abbreviations

The following abbreviations are used on charts to indicate radar aids to navigation :

Ra.	Coast Radar Station.
Racon.	Radar Responder Beacon.
Ra. Reffl.	Radar Reflector.

Part IV—AIR NAVIGATION

CHAPTER XIII

FUNDAMENTAL PRINCIPLES

1. DEAD RECKONING

The navigation of an aircraft, like that of a ship, consists of Dead Reckoning, supplemented by observations of terrestrial objects and heavenly bodies. From Chap. II one can appreciate the allowance which must be made at sea for the effect of tidal streams, etc., and, in exactly the same way, the position of an aircraft in flight is dependent on its own course and speed—as affected by the direction and speed of the wind. It is thus necessary for the air navigator to consider six primary factors :

(*a*) **The Course** (**Co.**). This is the direction in which an aircraft is heading, and it must be named *T*, *M* or *C* according to whether it is True, Magnetic or Compass (p. 21).

(*b*) **The Air Speed.** This is the speed at which an aircraft passes through the air, and it is measured by an *Air Speed Indicator* (p. 124) calibrated in either m.p.h. or knots.

(*c*) **The Wind Direction.** This is the direction *from* which the wind is moving (e.g., an EAST wind blows *from* the EAST), and it is always given with reference to the *true* meridian.

(*d*) **The Wind Speed** (**W/S**). This is the rate of the wind's movement relative to the ground, and is generally given by meteorologists in miles-per-hour.

(*e*) **The Track** (**Tr.**) This is the direction of the path of an aircraft *over the ground.* The direction which it is intended to follow is called the *Required Track*, while the *Track Made Good* is the path actually traced. Like a Course, it can be True, Magnetic or Compass but it will only coincide with the Course when there is a head-wind, tail-wind or no wind at all. Under other conditions the wind will cause the aircraft to pass sideways over the earth. The difference between the Course and Track is called the *Drift*, and can be measured with the *Drift Recorder* (p. 126).

(*f*) **The Ground Speed** (**G.S.**). This is the speed of an aircraft *over the earth*, and it can be obtained with either the Drift Recorder or by applying the known wind to the air speed.

If any four of the above factors are known, the other two can be determined by the construction and measurement of a *triangle of velocities* as shown in fig. 3. When drawing such diagrams, it is essential to mark them in the conventional manner for air navigation—with one arrowhead on the Course vector, two on the Track vector and three on the Wind vector. In air navigation, however, as many problems as possible should be solved mechanically, and for this purpose a useful aid is the circular slide rule or computor, such as the *Dalton Dead Reckoning Computor* (R.A.F. Mk. III), designed in the U.S.A. by Philip Dalton, which uses the graphical method of solving vector problems.

2. MAP READING

In addition to his navigational chart, the use of which has already been explained, the air navigator also has a topographical map—simply for the purpose of map reading. It is essential to stress that such maps should not be used for plotting, for, in addition to their details being confusing, lines drawn on them do not represent rhumb lines on the earth. As with chartwork, the essence of map reading is thorough familiarity with the conventional signs, which are generally printed in the margins of the map sheet. The most important of these are probably the methods of showing the height and disposition of mountains and hills. These are generally indicated with either contour lines, layer tinting, shading, hachures or spot-heights. Maps should be aligned in the correct direction, so that their meridians lie in a true North-South line, and the aim of the navigator should always be to anticipate everything before it shows up.

Another exceedingly important factor to be considered is the *scale* of a map. This is the relationship between a given distance on the ground and the map length which represents that distance. Scale can be expressed by a graduated line, a statement in words (e.g., " Four miles to One Inch ") or a *Representative Fraction.* The latter is the ratio of a unit length on the map to a corresponding number of similar units on the earth. Hence 1/250,000 means one unit on the map is equivalent to 250,000 such units on the earth. Maps are thus often spoken of as " the million map," " the half-million map " or " the quarter-million map."

CHAPTER XIV

NAVIGATIONAL INSTRUMENTS

This chapter describes the principal instruments commonly found in aircraft for the purposes of navigation (other than automatic flight).

1. COMPASSES

(*a*) **The Magnetic Compass.** Based on the principles outlined in Chap. I, the P4 and smaller P6 aircraft magnetic compasses consist of a magnet system freely pivoted in a bowl filled with liquid. Attached to the magnet system are a number of damping wires, which offer resistance to the liquid and define the cardinal and quadrantal points. The cardinal wires carry small glass tubes containing a luminous compound, and the N wire is distinguished by a cross-piece. Unlike the mariner's compass, there is no card attached to the magnet system,* but instead an external grid ring can be rotated around the top of the bowl. This is graduated like a normal card, and can be orientated relative to the magnet system by parallel luminous grid wires. In addition to Variation, Deviation and Dip, an aircraft magnetic compass is also affected by alterations in course and speed, which have the worst results when turning on Northerly courses in the Northern hemisphere, and Southerly courses in the Southern hemisphere. These errors are counteracted in—

There is however a Bearing ("O") Compass fitted with a card and azimuth circle* (*b*) **The Distant Reading (D.R.) Compass. This consists of a Master Unit, situated generally in the tail, well away from the main sources of deviation around the cockpit. It comprises a small gyroscope, rotated electrically at about 12,000 r.p.m., which provides a fixed datum whereby changes of course can be measured. Any such change alters the angle between the gyroscope's axis and the aircraft's fore-and-aft line. This starts an electric motor driving a transmitter system which indicates the alteration of course on up to six repeaters, throughout the aircraft. Underneath the gyroscope is a pivoted North-seeking magnet which is aligned with the local magnetic meridian. The repeaters can thus be made to show the *magnetic course*, though the *true course* can be indicated instead by adjusting a *Variation Setting Corrector* installed between the repeaters and master unit.

(*c*) **The Pioneer Magnesyn Compass.** This is a remote indicating magnetic compass not gyro-stabilized and therefore subject to the turning and acceleration errors described in Section (*a*) above. Its master unit comprises a magnet enclosed in a float chamber fitted with damping vanes, suspended on a pivot and supported by a spring-loaded pivot cup. The compass system is in a liquid filled chamber almost spherical in shape, and connected to an upper chamber which forms a bubble trap, and which is sealed by a diaphragm. Below the compass bowl, and having no mechanical connection with the magnet system is the *Magnesyn* transmitting element. This consists of a ring of permalloy on which is wound a coil fixed rigidly to the case. The relative position of the coil and magnet, which is dependent on the aircraft's heading, is reproduced in up to three repeaters, each consisting of a coil with a magnet in the centre.

(*d*) **The Fluxgate Compass.** This is a gyro-stabilized remote indicating compass for undisturbed azimuth indication in flight. It consists of three independent units—or *Fluxgates*, mounted in the form of a triangle and stabilized horizontally by an electrically driven gyroscope. In each fluxgate there is an induced electromotive force (e.m.f.) dependent upon its position relative to any external field. Any turn of the aircraft alters the e.m.f. in each fluxgate and this is relayed to a master indicator where it is translated directionally by an independent search coil. Provision is made at the master indicator for mechanical correction of deviation and variation, and repeaters are run from a magnesyn transmitting system.

2. ALTIMETERS

(*a*) **The Barometric Altimeter.** If an aneroid barometer is taken up in an aircraft, the pressure it measures (in millibars) will be found to fall as the height increases (the average rate is 1 mb. per 30 ft.). By graduating the scale of the instrument in feet instead of millibars one is thus provided with a simple altimeter. The pressure of the atmosphere outside the aircraft is led into the instrument where pressure changes cause the expansion or contraction of an elastic metal capsule which is almost a vacuum. The movements of the capsule are transmitted via a lever and arm to a bell-crank which turns the indicator pointer. The dial can be rotated by means of a knob, and in this way the altimeter should always be set, before taking-off, to the height of the aerodrome above sea level. Changes of temperature in the aircraft are compensated by a bi-metal strip, consisting of two metals of different co-efficients of expansion. Calibration for the variation of temperature with height can be made with the aid of a computor, or by adding or subtracting 1 per cent. of the indicated height for every 5° the mean temperature is above or below 50° F.

(*b*) **The Sensitive Altimeter.** This is an improved version of the above instrument, which possesses three pointers indicating hundreds, thousands and tens of thousands of feet. Its high sensitivity is gained by means of three capsules, special low friction bearings and balanced levers. At the bottom of the dial is a small window, through which appears a subsidiary scale graduated in millibars. When the atmospheric pressure is set on this, the altimeter should register zero. This is of great use when approaching an aerodrome in poor visibility—for, if the pressure at the landing position is ascertained and applied to the scale, then the instrument will show an accurate height above the ground during the approach and landing.

(*c*) **The Radar Altimeter S.CR 718.** This measures by radar the height of an aircraft above the ground to an accuracy of about 20 feet. As with the echo-sounder (page 64) the height is proportional to the time-lag between the transmission of a pulse and its return on reflection by the ground. The outgoing signal and its echo are adjusted on a scale surrounding a cathode-ray tube, so that the pulse coincides with zero, and the height is thus shown opposite the echo. The instrument is of particular importance in high altitudes, when practising *Pressure Pattern Flying*, or *Aerologation*, i.e., flying around some meteorological system, so as to get the maximum assistance or minimum interference from the wind.

3. AIR SPEED INDICATORS

(*a*) **The Air Speed Indicator** (A.S.I.) Like the log in a ship, this instrument determines the speed of an aircraft through the air—as opposed to over the ground. The underlying principle is that the air-stream pressure varies approximately as the square of an aircraft's speed. This indicator therefore measures the pressure of the air-stream on an open-ended tube, or *Pitot Head* (pronounced *Peeto*). Thence it is led to a metal capsule which expands or contracts, and transmits its movements by levers to a pointer on a graduated dial. The inside of the instrument must be kept at atmospheric pressure, and is thus connected to a *Static Head*, or closed tube with holes in its sides. The Pitot and Static Heads together form what is called the *Pressure Head.* This is often electrically heated to avoid ice accretion, and sometimes the Pitot has a filter incorporated to eliminate dirt. At its rear end there is also a small hole which allows moisture to pass into the Static Head, and thence through the holes into the air.

The instrument should be located in a forward position, well clear of the slipstream and other air disturbances. Rarely, however, is it possible to place it where it is entirely free from these effects, and it is thus necessary to use the most suitable place, and then compute by means of tests the *Position Errors* for various speeds. In practice these are combined on a card with any inherent *Instrument Error*, and also an *Attitude Error*, which allows for the angle of the Pressure Head to the airflow ; this is only appreciable if exceeding 10°. The total correction applied to the indicated air speed gives the *Rectified Air Speed*, and this likewise must be corrected from a *Height and Air Speed Computor*, to allow for altitude, temperature and density. An approximate correction can be made by adding 1.75 per cent. of the R.A.S. for every 1,000 feet of altitude. Thus the *True Air Speed* (*T.A.S.*) can be obtained from the equation $T.A.S. = R.A.S.\frac{(57 + X)}{57}$ where X is the height in thousands of feet.

(*b*) **The Air Mileage Unit (A.M.U.).** Due to the errors mentioned in the last paragraph, it can be seen that the difference between Pitot and Static pressures, measured by the A.S.I., is not directly proportional to the True Air Speed. In the A.M.U. a fan is employed to build up a pressure to balance that at the Pitot Head. If the air fed to the fan is of the same density as that outside, then the rotational speed of the fan is proportional to the T.A.S. The Pitot and fan pressures are fed to the opposite sides of a diaphragm, the movement of which operates an electrical contact in the fan motor circuit. This governs the fan speed and consequently the fan pressure necessary to balance any changes in the Pitot pressure. This instrument can be incorporated with a D.R. compass into an *Air Position Indicator* (*A.P.I.*), which provides a continuous and automatic airplot, by resolving the course and air mileage into N-S and E-W components.

4. DRIFT MEASUREMENT

(*a*) **The Drift Recorder.** This is an instrument for determining the *Drift*—or difference between an aircraft's *course* and *track* (p. 118). It consists of a periscope fitted over the side of the aircraft, which produces an image of the ground beneath. On one side of the eyepiece is a roughened glass plate, on which is a pencil attached by a parellel-motion device to a pointer in the eyepiece. By moving the pencil one can make the pointer follow ground objects as they cross the field of view. The resultant pencil line is compared with a number of lines on a grid plate, which can be rotated beneath it, and in this way the Drift is read off against an index mark. Eight hundred feet is the lowest height at which Drift can be taken at all accurately with a speed of about 150 m.p.h. Pencil marks should be removed with a damp rag, and the pointer is luminized so that the instrument can be used at night.

The periscope is fitted with two transverse timing lines, and, when a Drift has been taken, and the grid plate lined up, the passage of ground objects beneath these lines can be timed with a stop-watch. The speed *over the ground* can then be calculated by means of the circular computor provided. In practice, the true height is set on the outer computor scale, and the time of passage in seconds on the inner one. Against the appropriate pointer on the outer scale will be found the Ground-Speed in knots or miles per hour.

(*b*) **The Stabilized Drift Meter.** This instrument possesses a gyroscope, which stabilizes an illuminated graticule in the horizontal plane, so that it is not affected by the roll or pitch of the aircraft. An optical system superimposes an image of the graticule on to the observer's field of view.

5. THE SEXTANT

As it is often impossible to view the sea horizon, the marine sextant of Chap. VI is generally replaced in aircraft by the *Bubble Sextant.* This employs an artificial horizon, formed by a bubble trapped in liquid and electrically illuminated at night. The method of operation entails viewing a celestial body through the exact centre of the bubble when the sextant is held level. It is most important not to wait for the bubble to settle down, as it is then greatly subject to accelerations. It is also essential, during an observation, that the aircraft should accurately maintain a constant course and airspeed.

The R.A.F. Bubble Sextant Mk. IXA embodies a clockwork timing device which averages 60 sights in two minutes. On the left side of the instrument are the bubble system, clutch and left handle, containing a dry battery and lighting switch. On the right side are the two mirrors, the apparatus for measuring their rotation, and the averaging mechanism. Observations taken in this way are normally calculated in the manner outlined in Chap. VIII.

6. GENERAL RADIO-NAVIGATIONAL AIDS

(*a*) **Primary Radar.** This presents a " picture " of the main features of the ground beneath an aircraft. The principle is the same as that explained in Chap. XII.

(*b*) **Cloud and Collision Warning Equipment.** This is a primary radar installation, the pulses of which are reflected by high ground (range 40 miles), other aircraft (5-12 miles) and Cumulo-Nimbus Clouds (40 miles).

(*c*) **Distance Measuring Equipment (D.M.E.).** This is a form of secondary radar, similar to that described in Chap. XII. An equipment in current general use is *Rebecca*—a very high frequency airborne interrogator, which provides heading and distance indication with respect to a ground or airborne responder such as *Eureka.* The interrogator incorporates a cathode-ray tube with a vertical trace. This has three range scales of 0-9 miles, 9-36 miles and 36-90 miles. A scale is selected by means of the right-hand " Time Base Switch," and the 36-90 ranges are read from the 0-9 scale (with values multiplied by ten). An approximate indication of the bearing of the responder beacon is given by the amplitude of the blip on either side of the trace. It is thus possible to " home " on a beacon by maintaining the equi-amplitude of the port and starboard blips. Under such circumstances bearings can be estimated to ±5°. The effective range of the system is dependent on the height of the aircraft, the height of the Eureka aerials, and the nature of the intervening terrain between the aircraft and beacon. The latter also becomes saturated when responding to more than about 40 aircraft, when clutter becomes excessive.

(*d*) **Space Pattern Systems**—Consol, Gee, Loran, Decca Mk. VI (see Chap. XII).

(*f*) **Radio Range.** A medium-frequency radio beacon, which emits a number of beams in fixed directions. They are used principally in the U.S. to indicate busy air routes, and when the pilot is flying on the beam he hears a continuous note. Outside the beam, a repeated Morse " A " or " N " is heard—depending on which side the aircraft is flying.

7. APPROACH AND LANDING AIDS

(*a*) **Standard Beam Approach (S.B.A.).** This employs a beam as in the radio range described above, but there are also two marker beacons to indicate the distance from the runway—so that the pilot can adjust his rate of approach.

(*b*) **The Beam Approach Beacon System (B.A.B.S.).** This consists of a responder situated at the far end of a runway approach. On being correctly " interrogated " by an approaching aircraft, it broadcasts short pulses (dots) on the left-hand side, and long pulses (dashes) on the right of the approach line. The exact distance from the runway is shown on the graduated vertical scale of the aircraft's Rebecca C.R.T. screen ; and the approximate azimuth is obtained by comparing the amplitude of two blips of different width, formed by the dot-dash transmissions. A steady or equisignal beam is caused by an overlap of the dot and dash, and indicates that the aircraft is in line with the runway. It is always so arranged that the touch-down point is indicated on the C.R.T. screen by 1¾ nautical miles range, irrespective of the length of the runway. If correct technique is carried out, B.A.B.S. will position the aircraft directly above the downward end of the runway at a height of 150 feet. Overshoot procedure is provided for, and the beacon, which can respond to about 30 aircraft at once, has a range of approximately 14 miles, dependent on height.

(*c*) **Instrument Landing System (I.L.S.).** This is a civil form of the military *SCS* 51, and covers both the azimuthal and glide portions of the approach —by means of two very high frequency radiobeacons. There are also three 75 mc./s. markers so that the distance of the aircraft from the runway can be checked. The visual indicator in the aircraft consists of a dial with two moving pointers and a central mark. Using these, it is possible to tell whether the aircraft is heading off the runway, or flying too high or too low —according to whether the pointers cross each other above or below, to the left or to the right of the mark.

(*d*) **Ground Control Approach (G.C.A.).** With this system, a controller on the aerodrome ascertains the position of an aircraft with primary radar. By means of radio-telephony, he can thus " talk down " the aircraft into a position for landing.

CHAPTER XV

NAVIGATIONAL REGULATIONS

1. RIGHT OF WAY

Chapter IV summarizes the nautical systems of lights, signals and rule of the road, as prescribed in the *International Regulations for Preventing Collisions at Sea.* In a like manner, this chapter will deal with Schedule II of the *Air Navigation Order*, 1949. It is stressed, however, that in both cases this book only summarizes, and in no way provides an alternative to careful study of the regulations.

A table is given on pages 135-137 showing the most common navigation lights likely to be encountered in the air, and following are briefly the rules regarding right of way : flying machines give way to airships, gliders and balloons ; airships give way to gliders and balloons ; gliders give way to balloons. When two aircraft of the same class are at approximately the same altitude, the aircraft which has the other on its right shall give way ; nevertheless, mechanically driven aircraft give way to aircraft seen to be towing other aircraft. The aircraft which has the right of way shall normally maintain its course and speed—though, when two aircraft are approaching head on and there is danger of collision, each shall alter its course to the right.

2. AIR TRAFFIC RULES

(*a*) **Taking Off.** Every aeroplane shall normally take off in the direction indicated for landings. When landings and take offs are not confined to a runway, an aeroplane shall leave clear on its left any other aeroplane taking off.

(*b*) **Air Routes.** An aircraft following a line of landmarks on the ground should keep such a line 300 yards on its left. Similarly, if following a track indicated by a directional radio guide, it should navigate so as to keep the centre line of such a guide to the left.

(*c*) **Safe Altitudes.** No aircraft may fly over any town at an altitude of less than 1,000 feet above the highest obstacle within a radius of 2,000 feet. Furthermore, no aircraft should fly without permission over any place where a large number of persons may be assembled.

(*d*) **Landing.** Every aeroplane must land in the direction indicated by a Landing " T " (or at night by lights), but if no " T " is exhibited then landing should be made into the wind. Where landings are not confined to a runway, an aeroplane must leave clear on its left any other aeroplane which is landing, landed or about to take off. If, after landing, an aeroplane requires to turn, it should do so to the left.

3. Movement Signals and Ground Marks

The customary visual signals to aircraft for traffic control are as follows :—

(*a*) **Intermittent Green Luminous Beam.**

1. An aeroplane on the ground is authorised to move on the manoeuvring area, but not take off.
2. An aeroplane in flight should return to the aerodrome and await permission to land.

(*b*) **Continuous Green Luminous Beam.**

1. An aeroplane on the ground is authorised to take off.
2. An aeroplane in flight is authorised to land.

(*c*) **Intermittent Red Luminous Beam.**

1. The aerodrome is unfit, and an aeroplane in flight should land elsewhere.
2. An aeroplane or vehicle on the landing strip must move clear.

(*d*) **Continuous Red Luminous Beam.** (or red pyrotechnic light or red flare). Landing, taking off, or any movement on the manoeuvring area is temporarily prohibited.

(*e*) **Ground Marks.** The direction of landing and taking off is generally indicated in daytime by a horizontal " T." Landing should be made up wind, and normally (but not necessarily) the shaft of the " T " lies along the direction of the wind—with the cross arm at the end from which it is blowing. When aeroplanes are required to land on a runway a horizontal white dumb-bell-shaped device is displayed. A white cross at each end of a runway indicates that it is unfit for use.

4. AERODROME LIGHTING

Runway aerodromes are illuminated at night by not less than six fixed lights at the edges of the runway (where the runway is more than 150 feet wide, the lights may be inset in lines parallel to the edges). In addition, the approach end of the runway may be indicated by runway " threshold lights " or " angle of approach lights."

At non-runway aerodromes the landing strip can be illuminated in one of three ways :

(*a*) By floodlight, an illuminated landing " T " and white boundary lights.

(b) By fixed lights in the form of a " T." The foot of the letter indicates the point of touch-down, and the cross arm shows where the run should be completed. Landings should be made to the right of the " T."

(*c*) Two lines of fixed lights.

SHORT BIBLIOGRAPHY OF RELEVANT ALMANACS AND TABLES

ANNUAL PUBLICATIONS

The Nautical Almanac, abridged for the use of Seamen. H.M.S.O., London.

The Air Almanac, H.M.S.O. London.

Brown's Nautical Almanac, edited Capt. C. H. Brown, Brown Son & Ferguson Ltd., Glasgow.

Reed's Nautical Almanac, edited Capt. O. M. Watts, T. Reed & Co. Ltd., Sunderland.

Admiralty Tide Tables, Hydrographic Department, Admiralty, London.

Tide, Distance and Speed Tables, Brown, Son & Ferguson Ltd., Glasgow.

TABLES PUBLISHED IN GREAT BRITAIN

BAIN, J.	*Bain's Star Altitude and Azimuth Tables*, Brown, Son & Ferguson Ltd., Glasgow, 1928.
BLACKBURNE, H. S.	*Excelsior Ex-Meridian and Position Finding Tables*, Brown, Son & Ferguson Ltd., Glasgow.
BLACKBURNE, H. S.	*Tables for Azimuths, Great Circle Sailing and Reduction to the Meridian*, Brown, Son & Ferguson Ltd., Glasgow.
BURDWOOD, J.	*Completed Burdwood Azimuth Tables*, Brown, Son & Ferguson Ltd., Glasgow.
BURTON, S. M.	*Four-Figure Navigation Tables*, G. Philip & Son, Ltd., London.
BURTON, S. M.	*Nautical Tables*, G. Philip & Son, Ltd., London.
COMRIE, L. J.	*Hughes' Tables for Sea and Air Navigation*, H. Hughes & Sons, Ltd., 1938.
GOODWIN, H. B.	*Azimuth Tables for the Higher Declinations*, Brown, Son & Ferguson, Ltd. Glasgow ,1925.
INMAN, J.	*Nautical Tables*, re-edited by W. Hall, D. Petter, 1947.
LECKY, S. T. S.	*Danger Angle and Off-Shore Distance Tables*, G. Philip & Sons, Ltd., London.
MOXLY, S. H. S.	*Coastal Tables for Use in Sight of Land*, Brown, Son & Ferguson Ltd., Glasgow, 1941.
MYERSCOUGH & HAMILTON	*Rapid Navigation Tables*, Sir Isaac Pitman & Sons Ltd., London, 1939.
NORIE, J. W.	*Nautical Tables*, revised, G. P. Burris, Imray, Lowrie, Norie & Wilson Ltd., 1948.
PINTO, J. CARLOS	*Simplex Navigation and Aviation Tables*, Brown, Son & Ferguson Ltd., Glasgow.
AIR PUBLICATION 1618	*Astronomical Navigation Tables*, H.M.S.O., London, 1948 (previously obtainable only through the Air Ministry).

TABLES PUBLISHED BY THE U.S. NAVY HYDROGRAPHIC OFFICE, WASHINGTON

H.O.9	*Bowditch's Tables.*
H.O.208	*Navigation Tables for Mariners and Aviators*, 1928.
H.O.211	*Dead Reckoning Altitude and Azimuth Tables.*
H.O.214	*Tables of Computed Altitude and Azimuth*, 1937.
H.O.249	*Star Tables for Air Navigation*, 1947.

INDEX

A.B.C. Tables, 82
Aerologation, 124
Air Mileage Unit (A.M.U.), 125
— Position, 125
— Position Indicator (A.P.I.), 125
— Speed Indicator, 124
Altitude-Azimuth, 74, 85
AN/CPN.6, 107
Apparent Solar Time, 68
Aries, First Point of, 69
A.T.M.C., 27
Azimuth Bearing, 24
— Circle, 19

B.A.B.S., 129
Barometric Altimeter, 122
Bearing, 21
Binnacle, 19
Bowaitch'a Tables, 78
Bubble Sextant, 127
Buoyage, 49 ff.
Burton's Tables, 78

Caph, 92
Celestial Sphere, 67
Chart Comparison Unit, 106
— Correction, 33
Cocked Hat, 40
Compass, 17 ff., 120 ff.
— Error, 20
Consol, 101
Convergency, 98
Corner Reflector, 106
Course, 34 ff., 117
Current, 56

D.Lat. & D.Long., 38, 39
Dalton Computor, 118
Datum Level, 58
Day Mark, 48
Dead Reckoning (DR.), 38
Decca Navigator, 111 ff.
Deck-Watch, 69
Declination, 24, 67, 79 ff., 89
Departure, 38
Deviation, 20
Dip, 20
Distance Measuring Equipment, 128
Distant Reading Compass, 121
Double-Day Tides, 59
Doubling Bow Angle, 41
Dreisonstock's Tables, 86 ff.
Drift, 56, 62, 118
— Recorder and Meter, 118, 126
Duration, tidal, 58
Dutchman's Log, 44

" E," 24, 68, 79 ff.
Ebbing, 57
Echo Sounder, 64
Eichelberger's Catalogue, 77
Ephemerides, 24, 79
Equation of Time, 68
Equinox, 58, 69
Establishment, 61
Estimated Position, 36, 39
Ex-Meridian, 90

Fix, 39
Flooding, 57
Fluxgate Compass, 122
Four-Point Bearing, 42
Full-&-Change, 61

Gee, 109
G.H.A., 84
Gimbals, 19
G.M.T., 24, 68, 69, 79
Gnomonic Projection, 30
Great Circle, 29
Ground Control Approach, 130
— Speed, 118
Gulder, 59
Gyro Compass, 28
— Magnetic Compass, 121

H.A.T.S., 68
Haversine, 73, 78 ff.

Horizon Distance, 43
Horizontal Angle, 41
Hour-Angle, 24, 67, 73, 83
Hydrolants, 32
Hydropacs, 33

Index Error, 70
Inset, 57
Instrument Landing System, 130
Intercept, 71, 74, 82 ff.
Isogonic Lines, 31

Knot, 31

Latitude, 30
Lattice Chart, 101, 109
Leading Mark, 51
Lead Line, 62 ff.
Lecky's Tables, 43
L.H.A., 85
Lighthouses & ships, 47, 48
Log-Ship, 44
Longitude, 30
Loran, 110
Lubber's Line, 19
Lunitidal Interval, 61

Magnesyn, 121
Magnetic Bearing, 21
— Compass, 17, 120
Map Reading, 118
Marc. St. Hilaire, 78
Mean Latitude, 38
— Time, 24, 68
Mercator's Projection, 30, 99
Meridian, 30
— Altitude, 75, 89
Middle Latitude, 38
Moon, 84

Nautical Almanac, 24, 78 ff.
— Mile, 30
Naveams, 32
Navigation Lights, 53
Neaps, 58
NEMEDRI, 32
Notices to Mariners, 33

Observed Position, 75
Orthodrone, 29

Parallels, 30
Pilots, 32
Pioneer Compass, 121
Pitch, 45
Pitot Head, 124
Planets, 67, 82, 84
POLARIS (Pole Star), 75, 88, 92
Position-Fixing, 108
— Line, 39
P.P.I., 105
Pressure Head, 124
Pattern Flying, 124
Projection, 30

" R," 82
Racon, 107
Radar, 103 ff., 127
— Altimeter, 123
Radiobeacons, 100
Radio Range, 129
Range, tidal, 58
Rebecca, 128
Rectified Air Speed, 125
Reduction, 90
Rendezvous, 37
Representative Fraction, 118
Required Track, 118
Rhumb Line, 29, 119
Right Ascension, 67, 83
Rise, tidal, 59
Rose, compass, 31
Rude's Star Finder, 77
Rule of the Road, 51
Running Fix, 40

S.A.N. Tables, 74, 86
Scale, 119
Secondary Ports, 60
Sensitive Altimeter, 123
Set, 56
Sextant, 69, 127
— Altitude, 70
Shoran, 110
Shore Effect, 98
Sidereal Hour Angle, 84
— Time, 69, 82
Sights, 67 ff.
Slack Water, 56
Slip, 45

Small Circle, 29
Sonne, 101
Sound Echo Distances, 43
Sounding Machine, 63
Soundings, 42, 58, 62
Sound Signals, 53
Space Pattern Systems, 128
Speed Made Good, 33
— Estimation of, 44
Springs, 58
Stand, 57
Static Head, 124
Stellar Observations, 76
Stuart's Distance Meter, 42
Sub-Stellar Point, 67
Swinging, 22

Tabulated Altitude, 85
Tidal Constants, 60
— Differences, 60
— Stream, 56
Tide, 56
— Tables, 56, 59 ff.
Topmark, 49, 50
Track, 118
— Made Good, 118
Transit, 23, 51
Traverse Table, 38
True Air Speed, 125

Variation, 19
— Chart, 31
Vertical Angle, 42
Vignot Principle, 37

Weir's Azimuth Diagram, 24, 82
Weymouth - Cooke Rangefinder, 42
What Star Is It ? 77
Wind Speed, 117
Wreck Marking Vessels, 48

Zenith, 67
— Distance, 67, 72, 81 ff., 89, 92

SPERRY EQUIPMENT

The practical basis of navigation

SPERRY MARINE INSTRUMENTS AND EQUIPMENT are recognised the world over as the essentials of accurate navigation.

SPERRY MARINE GYRO COMPASSES provide a navigational reference to true North undisturbed by magnetic influences. Both the Mk. XIV for larger ships and the Mk. E1 (Sperry Minor) for smaller vessels will transmit to bearing repeaters, Course Recorders and Gyropilots for automatic steering.

SPERRY AUTOMATIC STEERING SYSTEMS provide accurate automatic steering with consequent saving in man-power, fuel, and time. Available for installation in new vessels or for coupling to existing steering systems.

SPERRY AIRCRAFT INSTRUMENTS AND EQUIPMENT, fitted as standard on most of the world's major air undertakings, civil and military, include Gyro-Magnetic Compasses (Gyrosyn), Artificial Horizons, Directional Gyros and Automatic Pilots.

SPERRY

THE SPERRY GYROSCOPE COMPANY LIMITED

GREAT WEST RD., BRENTFORD, MIDDX. Tel.: EALing 6771

Illustrated is the 12 ft Runabout Launch

E. W. LIGHTCRAFT

SIX MODELS OF LIGHT ALLOY . . .

Light • Strong • Non-corrosive • Minimum maintenance

9 ft. General Purpose Dinghy	£46 10 -
9 ft. Sailing Dinghy	£69 10 -
12 ft. General Purpose Dinghy	£65
12 ft. Sailing Dinghy	£97 10 -
12 ft. Bermudan Cat Rig Sailing Dinghy	£97 10 -
12 ft. Inboard Dinghy (4 h.p. engine)	£192
(with 8 h.p. engine)	£245
12 ft Decked Runabout Launch (4 h.p. engine)	£262 15 -
(with 8 h.p. engine)	£325

Write for illustrated folder

EUSTACE WATKINS LTD.

Showrooms: 12 Berkeley Street, W.1. Telephone: Mayfair 5951
Trade Enquiries 12 Chelsea Manor Street, S.W.3. Telephone: Flaxman 8181

James Brown (Oxford) Ltd.

Wine and Spirit Merchants

11 Curzon Street, London, W.1

● ESTABLISHED 1865 ●

Telephone: Grosvenor 3327 and 3328

We will gladly send our current wine list on request

ALSO AT

OXFORD • GUILDFORD • SEVENOAKS • SOHO

Coloured Charts for Coastal Navigators

A series of 22 Charts covering the British Isles south of Fort William and Flamborough Head, together with the Continent from Cherbourg to Ymuiden. Sandbanks and Shallows are coloured to show depths, and in addition all courses are marked Magnetic in degrees and points, together with distances. Mounted on linen. Each Chart **12/6** net.

and the following publications for Navigators

Pilotage and Navigation for Little Ships

by B. R. KEIR MOILLIETT, M.A.

Navigation without Logarithms

by S. de NEUFVILLE, M.A.

EDWARD STANFORD LTD.

12-16 LONG ACRE, LONDON, W.C.2

WORLDWIDE INSURANCE SERVICE

ROYAL
INSURANCE
COMPANY
LIMITED

FOR ALL YOUR INSURANCE NEEDS

including

YACHT AND MOTOR BOAT INSURANCES

Head Offices :—

LIVERPOOL
1 North John Street, 2

LONDON
24/28 Lombard Street, E.C.3